THE ELEMENTARY SCIENCES

IN

CHAMBERS' EDUCATIONAL COURSE.

CHAMBERS' EDUCATIONAL COURSE.
NUMBER III.

ELEMENTS
OF
NATURAL PHILOSOPHY.

In Three Parts.

I.
LAWS OF MATTER AND MOTION.

II.
MECHANICS.

III.
HYDROSTATICS, HYDRAULICS, AND PNEUMATICS.

BY

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CHAMBERS' EDUCATIONAL COURSE.

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INTRODUCTORY OBSERVATIONS

BY THE

AMERICAN EDITOR.

The present volume is appropriately styled the "First Book of Natural Philosophy," because its subject should be understood by the learner before entering upon the study of either of the other departments of Physics. Moreover, it lies at the foundation of all natural science, and explains a multitude of the phenomena of nature and art, which earliest awaken the curiosity of children in their observation of natural objects, and in their various forms of amusement. The lessons here taught will enable parents or teachers to satisfy the inquisitiveness of children, who often manifest an ardent thirst for knowledge in the nature and causes of things. And a thousand opportunities occur, in simple and familiar occurrences transpiring in connection with the exercises of the school-room and the pastimes of the play-ground, of which teachers and scholars may avail themselves for creating a fondness for this beautiful science.

No subject so forcibly impresses the young with the evidence of a Supreme Being, or so strikingly shows the proofs of the Divine wisdom and goodness, as do the topics of this little volume—presenting thus to the admiration of children the grandest truths of moral science, and leading them to submit to the sublime teachings of revelation.

The catechetical questions in this, as in the other volumes, are so framed purposely as to admit of other and kindred questions on almost every topic which will readily occur to the teacher; while to the illustrations furnished by the author, other familiar examples may be superadded.

That this work may inspire teachers and pupils with a taste for kindred pursuits, and promote their intellectual and moral improvement, is the confident expectation of the editor.

D. M. R.

PREFACE.

The Laws of Matter and Motion, usually treated under the titles of Statics, Pyronomics (or Heat) and Dynamics, form not only the proper introduction to Natural Science, but that particular department of it with which it is of the most importance that all should be made familiar. For these reasons, they are here presented in a small distinct treatise, the price of which, as well as the simplicity of the language employed in its composition, may be expected to facilitate its general introduction into schools and families.

The remaining departments of Physics—Mechanics or Mechanical Powers and Machinery, Hydrostatics and Hydraulics, Pneumatics, Acoustics, and Optics, Electricity and Magnetism, Meteorology, and Astronomy, constitute distinct portions of this Educational Course, already, or about to be, published.

In exercising a class in this and other departments of Natural Science, it will be found to be of considerable importance to cause each paragraph to be mastered or thoroughly understood before proceeding to what follows; for the whole constitutes a structure in which each part rests on what has gone before it. The pupil should, also, not only *read*, but be induced to *think* on the nature of the principles which are unfolded, and led to find examples of their action in the every-day concerns of life, and the common phenomena of the universe.

To facilitate exercises, and afford a ready means of reference, each paragraph is numbered. [And to add still greater facilities both to teachers and learners, each page is furnished with analytical questions.]

CONTENTS.

NATURAL PHILOSOPHY.

MATTER AND MOTION.

OF MATTER AND ITS PROPERTIES.

1. MATTER is a term applied to all things which are supposed to possess substance. We acquire a knowledge that things possess substance, through our senses, sometimes aided by the test of philosophical experiment.

2. Matter is organic, when it possesses organs or organized parts for sustaining living action. Matter is inorganic, when it has no organs or organized parts to sustain living action. Animals and plants are organic matter; a stone is inorganic matter.

3. Portions of matter are called bodies. The air, water, the earth—a stone, a ball, an animal, a tree—any substantial thing, which we can distinguish from other things—are bodies.

4. When any portion of matter excites any of our senses, the feeling of which we are sensible is called a *sensation;* and our knowledge of the existence of the exciting cause, resulting from this sensation, is called a *perception.*

5. The qualities which bodies possess of exciting particular sensations, are called their *properties.*

6. The *phenomena* or appearances that take place in the material world, are considered to be the result of cer-

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1. What is matter, and how is it recognised?
2. Define organic and inorganic matter.
3. Explain bodies,—sensation, perception, properties, &c.

tain natural *laws*. A natural *law* is a rule, or principle, according to which the same event uniformly occurs under the same circumstances.

7. The natural laws which regulate the phenomena of inorganic matter and its properties, are sometimes called *physical* laws, from a Greek word signifying Nature; and the treatment of these laws is ordinarily expressed by the terms NATURAL PHILOSOPHY or PHYSICAL SCIENCE.

8. The constitution of a body is its state of being, or peculiar composition of properties and qualities. We cannot alter any of the properties or qualities of a body, without altering the constitution of the body. Bodies have certain properties, which are called *essential*. because they are invariably found in bodies. The essential properties of bodies are *Impenetrability, Extension, Figure, Divisibility, Inertia, and Attraction.*

IMPENETRABILITY.

9. By *impenetrability*, it is meant that two bodies cannot occupy the same space at the same time. Each particle of matter occupies a certain space, and the same space cannot at the same time be occupied by another particle. What common language calls penetrability, is, in the philosophical sense, only a liability to have certain particles displaced. Thus a piece of dough is, in common language, penetrable by the finger; but in philosophical language, the act of thrusting the finger into a piece of dough would be called the displacing of as much of the dough as the space occupied by the finger. Perhaps the word *occupancy* would be a less ambiguous term for the philosophical idea of impenetrability.

10. There are cases in which a condensation takes place, when two fluids are mixed together. so that a considerable deal less space is occupied by the two together, than was occupied by them in a separate state. But this arises from a chemical combination having taken place; the particles of the substances, by the mysterious agency

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4. What of the constitution of a body?
5. Enumerate the essential properties of bodies.
6. Define impenetrability, and illustrate.

of chemical attraction, have been drawn closer together; thus, the whole fluid occupies less space than it did formerly. In the same way, a sponge, by being compressed, has its particles brought nearer to each other, and of course it has less bulk than it had before it was squeezed. Indeed, the hand and the sponge together may occupy the same space as the sponge did singly.

11. A nail, driven into a piece of wood or other soft material, under certain circumstances does not enlarge the general size of the body; but in penetrating it, it displaces its particles, and occupies the space which they occupied; and, accordingly, they are rendered more dense, or become more solidified, than they were before, just in the same way as the particles of the sponge when compressed. In the one case, the particles are condensed from without, and in the other from within. But these particles still occupy a certain quantity of space which cannot be occupied by other particles at the same time, for in every case in which the attempt is made, although this apparently seems to be effected, it will be found that the one has been removed to make way for the other.

EXTENSION OR MAGNITUDE.

12. All bodies which are observable by the senses, are found to occupy a certain portion of space—that is, they possess extension or magnitude; and those which are so small as to elude investigation in this manner, are considered by the understanding to possess it. Indeed, the impenetrability of matter presupposes its extension or magnitude. It is impossible to form a conception of matter, however minute may be the particle, without connecting with it the idea of its having a certain bulk, and filling a certain quantity of space.

13. In common phraseology, we express this property of bodies by the word size; but the most appropriate term is volume. Thus, we say the volume of a terrestrial or celestial globe is so many cubic inches. When the *lines*

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7. Examples of condensation, from without and within.
8. What of extension?

and *surfaces* of a body are spoken of, the external limits of its magnitude are implied. Lines are the limits which separate the several surfaces of the same body. They are also called edges. Thus, the line which separates the top from one of the sides of a box, is denominated an edge. The quantity of a surface is called its *area*, and the quantity of a line is termed its *length*. Thus, we say the area of a floor is so many yards; and the length of a rope is so many yards. Volume, area, and length, however, are sometimes expressed by the word magnitude.

14. The dimensions of magnitude or extension are usually entitled length, breadth, and depth; and they vary of course very considerably in different bodies, according to their shape. Height and depth are the same dimension, considered in different points of view. When a body is measured downwards, it is said to be so many feet deep; when measured upwards, it is said to be so many feet high. Breadth and width express the same dimension.

FIGURE.

15. The figure of a body is its shape or form. Figure or form is the result of extension, for we cannot have the idea of a body possessing length and breadth, without its having some kind of figure, however irregular. The volume of a body has no relation to its figure. Bodies which have the same figure may possess very different volumes; and bodies may have the same volume, but possess very different figures. Thus, two masses of matter may have the same volume, although the one be round and the other be square.

DIVISIBILITY.

16. Matter is divisible into parts, and these parts may again be subdivided into other parts. By this is meant divisibility or separability.

17. To the practical subdivision of matter there seems to be no assignable limit; and many of the instances of it

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9. Define volume, area, and length, &c.
10. What of figure?
11. Define divisibility.

which may be found in philosophical investigations, almost exceed credibility. The thinnest part of a soap bubble, which is a thin shell of water and the matter of soap, does not exceed, in thickness, the 2,500,000th part of an inch. The useful arts, also, furnish many striking examples; but it is in the organized world that the most astonishing proofs of the extreme divisibility of globules, or particles of matter, are to be found.

18. Animalcules—that is, animals which are so small as to be invisible to the naked eye, and which, by means of microscopes, are seen floating in water—are in some cases so minute, that it would require a million of them to form the bulk of a grain of sand. As these animalcules possess, in every case, a perfect organization to enable them to perform all the functions of life, the smallness of their different parts, and the extreme minuteness of the particles of matter which compose them, are too exquisite to be made the subject of calculation: the imagination is lost in the contemplation of their wonderful economy.

19. The effluvium or odour which excites the sensation of *smell*, consists of an incalculable number of particles of matter floating in the atmosphere, and so minute as to be altogether invisible to the eye. These particles are not more remarkable for their inconceivably small size than for the length of time which they will remain in suspension in the atmosphere, or in connection with some particular place. The effluvium given forth by a single grain of musk has been known to perfume a large apartment for twenty years, and yet at the expiry of that period there was no sensible diminution of the little mass of matter from which the smell had proceeded.

20. The diffusion of particles of matter invisible to the naked eye, is also obvious in the case of the melting of a piece of sugar in our tea: the solid mass of the sugar disappears, and the particles of which it was composed are diffused in the liquid. There is a similar diffusion of particles of salt in the ocean. When we look through a glass

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12. What example of divisibility is named?
13. What of animalcules, and of odours?

full of sea water, we perceive that it is pure and limpid; but if we pour the water into a vessel on the fire, and boil it, we shall at length discover that, while the liquid has escaped in the form of vapour, the particles of salt it held in solution remain encrusted on the vessel.

21. Particles of matter are never destroyed or lost, although they may disappear from our immediate observation. Under certain circumstances, the particles may again be collected into a body without change or form. Mercury, water, and many other substances, may be converted into vapour, or distilled in close vessels, without any of their particles being lost. In such cases, there is no decomposition of the substances, but only a change of form by the heat; and hence the mercury and water assume their original state again on cooling.

22. When bodies suffer decomposition or decay, their elementary particles, in like manner, are neither destroyed nor lost, but only enter into new arrangements, or combinations with other bodies. When a piece of wood is heated in a close vessel, such as a retort, we obtain water, an acid, several kinds of gas, and there remains a black, porous substance, called charcoal. The wood is thus decomposed, or destroyed, and its particles take a new arrangement, and assume new forms; but that nothing is lost, is proved by the fact, that if the water, acid, gases, and charcoal, be collected and weighed, they will be found exactly as heavy as the wood was, before distillation. In the same manner, the substance of the coal burnt in our fires is not annihilated; it is only dispersed in the form of smoke, or particles of culm, gas, and ashes or dust. Bones, flesh, or any animal substance, may in the same manner be made to assume new forms, without losing a particle of the matter which they originally contained. The decay of animal or vegetable bodies in the open air, or in the ground, is only a process by which the particles of which

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14. The example of solution.
15. How do you prove that nothing is lost by vaporization?
16. What becomes of the elements after decomposition?
17. In the case of wood, how is this shown?

they were composed change their places, and assume new forms.

23. The decay and decomposition of animals and vegetables beneath the surface of the earth, fertilize the soil, which nourishes the growth of plants and other vegetables; and these, in their turn, form the nutriment of animals. Thus is there a perpetual change from death to life, and from life to death, and as constant a succession in the forms and places which the particles of matter assume. Nothing is lost, and not a particle of matter is struck out of existence. The same matter of which every living animal and every vegetable was formed in the earliest ages, is still in existence. As nothing is lost or annihilated, so it is probable that nothing has been added, and that we ourselves are composed of particles of matter as old as the creation. In time, we must in our turn suffer decomposition, as all forms have done before us, and thus resign the matter of which we are composed, to form new existences.

24. Such are some of the remarkable phenomena connected with the divisibility of matter; and we are naturally led to inquire, Is matter infinitely divisible, or are there certain constituent atoms which are incapable of further division? The latter supposition is the one most generally admitted, yet there is no denying that it seems scarcely a legitimate inference. For however small a particle may be, we can easily conceive of one still smaller—for instance, by simply supposing that same particle halved. To the understanding, without reference to direct observation, it seems as absurd to assign limits to the divisibility of matter, as boundaries to space, which is considered infinite.

INERTIA.

25. Inertia means passiveness or inactivity. Thus, matter is perfectly passive in submitting to any condition in which it is placed, whether of rest or motion. When at rest, it shows an inability or reluctancy to move; and

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18. What of the reciprocal interchange between life and death?
19. What reflections are suggested?
20. Define inertia, both in rest and motion.

when in motion, it shows an equal inability or reluctancy to come to a state of rest.

26. It is obvious that a rock on the surface of the earth never changes its position in respect to other things on the earth. It has of itself no power to move, and would therefore for ever lie still, unless moved by some external force. Now, it is just as true that inert matter has no power to bring itself to rest, when once put in motion, as that it cannot put itself in motion, when at rest; for, having no life, it is perfectly passive, both to motion and rest, and therefore either state depends entirely upon external circumstances.

27. Many instances might be given of the tendency which matter has to remain in the condition in which it happens to have been already placed. The following are among the most instructive:—When the sails of a ship are loosened to the breeze, slowly and heavily at first the vessel gets into motion, but gradually its speed increases as the force by which it is impelled overcomes the inertia of its mass. A great force is necessary at first to set a vehicle in motion; but when once this is effected, it goes onward with comparative ease, so that, in fact, a strong effort is necessary before it can be stopped. If a person be standing in it when it is suddenly set a-going, his feet are pulled forward, whilst his body, obeying the law of inertia, remains where it was, and he accordingly falls backwards. On the other hand, if the vehicle be suddenly stopped, and the individual be standing in the same position as formerly, the tendency which his body has to move forward—for it acquired the same motion as the carriage by which it was borne along—will cause him to fall in the opposite direction. Casualties of this description frequently occur to persons on horseback, who are thrown over the necks of their steeds, or fall behind them, according as the animal stands still suddenly, or starts off unexpectedly. A man jumping from a coach at full speed will certainly fall prostrate on the ground, if he leaps down as

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21. What illustrations are cited?
22. To what casualties does this render us liable?
23. What of jumping from a coach in motion?

if he were descending from a body at rest, to one which is in the same state; for when he makes the attempt, his body has the same motion as the coach; and when the feet arrive at the ground, the motion in the lower part is arrested, whilst it continues in the upper part; and thus he finds himself thrown from the perpendicular into the horizontal position.

28. The following is a familiar example of the inertia of matter:—upon the tip of the finger let a card be balanced, and a piece of money—say a shilling—laid upon it. Let the card then be smartly struck, and it will fly from beneath the coin, leaving it supported upon the finger. This arises from the inertia of the metal being greater than the friction of the card which passes from beneath it.

29. Coursing, or hare-hunting, affords a striking illustration of inertia. In that field sport, the hare seems to possess an instinctive consciousness of the existence of this law of matter. When pursued by the greyhound, it does not run in a straight line to the cover, but in a zig-zag one. It *doubles*, that is, suddenly changes the direction of its course, and turns back at an acute angle with the direction in which it had been running. The greyhound, being unprepared to make the turn, and therefore unable to resist the tendency to persevere in the rapid motion which it has acquired, is impelled a considerable distance forward before it can check its speed and return to the pursuit. But, in the mean time, the hare has been enabled to shoot far ahead in the other direction; and although a hare is much less fleet than a greyhound, by this scientific manœuvring it often escapes its pursuer. Those who have witnessed horse-racing, may have observed that the horses shoot far past the winning-post before their speed can be arrested. This is also owing to the inertia of their bodies.

30. Common experience proving that matter does not put itself in motion, we might be led to believe that rest is the natural state of all inert bodies; but a few consider-

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24. What example is named?
25. What of racing and hare-hunting?

ations will show that motion is as much the natural state of matter as rest, and that either state depends on the resistance, or impulse, of external causes.

31. If a cannon-ball be rolled upon the ground, it will soon cease to move, because the ground is rough, and presents impediments to its motion; but if it be rolled on the ice, its motion will continue much longer, because there are fewer impediments, and, consequently, the same force of impulse will carry it much farther. We see from this, that, with the same impulse, the distance to which the ball will move must depend on the impediments it meets with, or the resistance it has to overcome. But suppose that the ball and ice were both so smooth as to remove as much as possible the resistance caused by friction, then it is obvious that the ball would continue to move longer, and go to a greater distance. Next, suppose we avoid the friction of the ice, and throw the ball through the air, it would then continue in motion still longer with the same force of projection, because the air alone presents less impediment than the air and ice, and there is now nothing to oppose its constant motion, except the resistance of the air.

32. If the air be exhausted or pumped out of a vessel by means of an air-pump, and a common top, with a small hard point, be set in motion in it, the top will continue to spin a considerable length of time, because the air does not resist its motion. A pendulum, set in motion in an exhausted vessel, will continue to swing, without the help of clockwork, for a whole day, because there is nothing to resist its perpetual motion but the small friction at the point where it is suspended.

33. We see, then, that it is the resistance of the air, and of friction, and of gravitation, which causes bodies once in motion to cease moving, or come to rest; and that dead matter, of itself, is equally incapable of causing its own motion, or its own rest.

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26. Describe the motion of a ball upon the ground and upon the ice.
27. How is motion affected by excluding the air?
28. What agencies combine to bring bodies to rest?

THE PROPERTIES OF MATTER CONTINUED.

ATTRACTION.

34. It is a fundamental law of nature, ascertained by Sir Isaac Newton, that every atom or particle of matter has a tendency to approach or to be attracted towards another atom or particle. This forms one of the leading principles in modern natural philosophy. Experience and observation demonstrate that this power of mutual attraction pervades all material things, and, though unseen except in its results, is ever present with us; is the cause of particles of matter adhering to each other, and forming solid masses—of these masses assuming in many instances a round or globular form—of the falling of bodies to, and their stability on, the earth—and is one of the causes of the whole of the planetary bodies moving in their paths in the heavens.

35. Attraction is of different kinds, although some of these may be merely modifications of others, and has received different names according to the circumstances under which it acts. The force which keeps the particles of matter together, to form bodies, or masses, is called *attraction of cohesion.* That which inclines different masses towards each other, is called *gravitation,* or *attraction of gravitation.* That which causes liquids to rise in tubes, or in very confined situations, is called *capillary attraction.* That which forces the particles of different kinds to unite, is called *chemical attraction.* That which causes the magnetic needle to point constantly towards the poles of the earth, is *magnetic attraction.* And that which is excited by friction in certain substances, is known by the name of *electrical attraction.*

36. Attraction of cohesion acts only at insensible distances, as when the particles of bodies apparently touch each other.

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29. What of attraction, and how manifested?
30. How many, and what kinds of attraction are named?
31. How does cohesion act, and in what forms of bodies?

37. This kind of attraction may be described as the quality in nature which causes matter to cohere or stick together. It is much stronger in some bodies than in others. It is stronger in the metals than in most other substances, and in some of the metals it is stronger than in others. In general, it is most powerful among the particles of solid bodies, weaker among those of fluids, and least of all, or almost entirely wanting, among elastic fluids, such as air and the gases.

38. Thus, a small iron wire will hold a suspended weight of many pounds, without having its particles separated; the particles of water are divided by a very small force, while those of air are still more easily moved among each other. These different properties depend on the force of cohesion with which the several particles of these bodies are united.

39. When the particles of a body can be suspended in the air in a fluid state, they will, if not under the attractive influence of some other body, arrange themselves by virtue of the same law, around a centre, and take a spherical or round form. Thus, a small quantity of dew suspended on the point of a thorn or leaf, becomes a globule, because in that case the attraction of the particles towards their own centre is greater than the attraction of any neighbouring body. Tears running down the cheeks, drops of rain, and hail, are all examples of this tendency in insulated fluid bodies to assume the globular form. When two perfect globules of mercury are brought into contact, they instantly unite together, and form one spherical drop. The manufacture of shot is also a striking illustration. The lead is melted and poured into a sieve, at the height of about two hundred feet from the ground. Each stream of lead, immediately after leaving the sieve, separates into little globules, which, before they reach the ground, are cooled and become solid: thus is formed the shot used by sportsmen. To account for the globular form in all these

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32. How is the difference illustrated?
33. What of the globular or spherical form?
34. How is this shown in shot-towers?

cases, we have only to consider that the particles of matter are mutually attracted towards a common centre, and in liquids, being free to move, they arrange themselves accordingly.

40. In consequence of this law of nature, it is considered probable that the planetary bodies, including our earth, were originally in a fluid state—that, in that state, they unavoidably assumed a spherical form, and were then hardened into their present consistency.

CAPILLARY ATTRACTION.

41. The force by which small tubes, or porous substances, raise liquids above their levels, is called Capillary Attraction, from *capilla*, the Latin word for a hair.

42. In a wet tea-cup, or other vessel containing liquid, you may perceive the liquid at the sides rising above the level of that of the other parts of the surface; this is caused by attraction.

43. If two glass plates be brought very near each other, so as to stand parallel with their flat sides in almost mutual contact, and then their lower end be dipped into a vessel of water, the fluid will rise up between the plates, and the height to which it rises will be greater the nearer the plates are to each other. The water rises very little on the outsides of the plates, for this attraction is insensible at even moderately small distances. If a glass tube, with an exceedingly small or capillary bore, be dipped in water, the fluid will rise in the interior of the tube; and the smaller the bore, the higher does the water ascend.

44. A great variety of porous substances are capable of this kind of attraction. If a piece of sponge or a lump of sugar be placed, so that its lowest corner touches the water, the fluid will rise up and wet the whole mass. In the same manner, the wick of a lamp will carry up the oil to supply the flame, though the flame is several inches

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35. What inference is thence drawn of the original state of the earth and other planets.

36. Define capillary attraction and give an instance.

37. What other illustrations are cited?

above the level of the oil. If the end of a towel happens to be left in a basin of water, it will empty the basin of its contents; and, on the same principle, when a dry wedge of wood is driven into the crevice of a rock, and afterwards moistened with water, as when the rain falls upon it, it will absorb the water, swell, and sometimes split the rock.

45. It is this kind of attraction which is supposed to be one of the causes of springs of water in the earth. The water creeps up by capillary attraction through porous beds of sand, small stones, and crevices of rocks, and in this manner reaches the surface even at great heights. The lower parts of the walls, and also the earthen floors of cottages, are in the same manner apt to become damp, by the attraction of the moisture upwards from the ground. Hence the necessity for clearing away all wet earthy matter from the foundations of houses.

CHEMICAL ATTRACTION.

46. The material world immediately under our observation, including such parts of the earth's crust as have been explored, the plants and animals upon the earth, and the atmosphere which envelopes it, is found to consist of fifty-four substances, just as all the words which compose a language are resolvable into a few letters. These substances, having hitherto resisted all endeavours to divide or resolve them into any others, are termed the *elements of matter*, or *simple bodies*. From the earliest stage of creation, most of them appear to have been in a state of combination with each other; they are scarcely ever naturally found otherwise; creation itself appears to have consisted in putting them into the associations which they have since commonly displayed.

47. Matter has ever been, and is now, undergoing perpetual decompositions and recombinations; some of which take place upon an extensive scale, as part of the regular functions and operations of nature, while others are affected

38. Between what portions of matter is chemical attraction exerted?
39. How many elements compose the universe?

by the ingenuity of man, to serve the purposes of his ordinary economy. Of the fifty-four simple substances, six are gases, forty-two are metals, and the remaining bodies are reducible under no fixed class. The investigation of the laws under which these various elementary bodies have formed the numerous compound substances which we see in nature, and the means by which compound substances can be resolved into their original elements, or thrown into new combinations, are the objects of the Science of CHEMISTRY.*

48. Chemical attraction, which is one of the leading principles in chemistry, takes place when particles of different kinds of matter unite, and the particles thus formed have properties in which they differ more or less from those substances by whose union they were formed. This species of attraction is also known under the name of *chemical affinity*, because it is said that the particles of substances, having an affinity for each other, will unite, while those having no affinity, do not readily enter into union.

49. It might almost be supposed that there are such things as preferences and dislikes among the particles of matter. Thus, if a piece of marble be thrown into sulphuric acid, their particles will unite with great rapidity and commotion, and there will result a compound differing in all respects from the acid or the marble. But if a piece of glass, quartz, gold, or silver, be thrown into the acid, no change is produced on either, because their particles have no affinity.

50. Shake sand and water in a bottle; whenever the agitation ceases, the sand falls; the water has no chemical action with it.

51. Suspend a piece of aqueous sulphate of copper (common blue vitriol) with a thread in a glass full of water. The particles of both combine, and form a stream

* See Reid's RUDIMENTS OF CHEMISTRY, forming parts of CHAMBERS'S EDUCATIONAL COURSE.

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40. Describe these in classes.
41. What of chemical affinity, illustrate this?

of blue fluid, which descends from the points where they are in contact. The solid is said to be *dissolved.* The compound is called a *solution* of the solid.

52. Sulphur and quicksilver, when heated together, will form a beautiful red compound, known under the name of *vermilion*, and which has none of the qualities of sulphur or quicksilver.

53. Oil and water have no affinity for each other, but potash has an attraction for both; and therefore oil and water will unite when potash is mixed with them. In this manner, the well-known article called *soap* is formed. But the potash has a stronger attraction for an acid than it has for either the oil or the water; and, therefore, when soap is mixed with an acid, the potash leaves the oil, and unites with the acid; thus destroying the old compound, and at the same instant forming a new one. The same happens when soap is dissolved in any water containing an acid, as the water of the sea, and of certain wells. The potash forsakes the oil, and unites with the acid, thus leaving the oil to rise to the surface of the water. Such waters are called *hard*, and are not good for washing, on account of the floating oil.

MAGNETIC ATTRACTION.

54. There is a certain ore of iron, a piece of which, being suspended by a thread, will always turn one of its sides to the north. This is called the *Loadstone*, or *natural Magnet;* and when it is brought near a piece of iron, or steel, a mutual attraction takes place, and, under certain circumstances, the two bodies will come together, and adhere to each other. This is called *Magnetic Attraction.* When a piece of steel or iron is rubbed with a magnet, the same virtue is communicated to the steel, and it will attract other pieces of steel, and if suspended by a string, one of its ends will constantly point towards the north, while the other, of course, points towards the south. This is called an *artificial* magnet. The *magnetic needle*

42. What experiments are here cited?
43. Define magnetic attraction, and its uses.

is a piece of steel, first touched with the loadstone, and then suspended so as to turn easily on a point. By means of this instrument, which is called the Mariner's Compass, the sailor is enabled to guide his ship through the pathless ocean.

ELECTRICAL ATTRACTION.

55. All nature appears to be pervaded by a mysterious affection, which bears the name of Electricity, in consequence of its having been supposed by the ancients to reside exclusively in *electron*, or amber.

56. In its ordinary state, electricity is invisible; but when excited, it assumes the appearance of a bright and subtile fluid. It is sometimes excited in very tremendous forms in the atmosphere; but it can be produced in less extent by mechanical means, particularly by the rubbing of amber, glass, silk, and a few other bodies.

57. When a piece of glass, or sealing-wax, is rubbed with the dry hand, or a piece of cloth, and then held towards any light substance, such as hair, or thread, the light body will be attracted by it, and will adhere for a moment to the glass or wax. The influence which thus moves the light body is called *Electrical Attraction.* When the light body has adhered to the surface of the glass for a moment, it is again thrown off, or repelled, and this is called *Electrical Repulsion.*

58. It is the nature of electricity to remain in a state of equilibrium or balance in all substances; and when one body happens to have more than its natural proportion, while another has less, there is a tendency in the surplus, in the one body, if sufficiently near, to rush to make up the deficiency in the other.

59. Electricity is the cause of the phenomena of thunder and lightning. In particular states of the atmosphere, generally in hot weather, the balance of electricity among the clouds, or between the atmosphere and the earth, is apt to become disturbed. If a cloud containing

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44. What of electricity, and its sources?
45. What of electrical attraction and repulsion?
46. How is an equilibrium produced?
47. What of lightning and thunder?

an overplus approaches or is attracted towards another which is undercharged—in other words, if a cloud *positively* electrified approaches one *negatively* electrified—the surplus flashes from the one into the other in the form of lightning, with a noise stunning to the ear.*

ATTRACTION OF GRAVITATION.

60. As the attraction of cohesion unites the particles of matter into masses or bodies, so the attraction of gravitation tends to force those masses towards each other, to form others of still greater dimensions.

61. The force of attraction increases in proportion as bodies approach each other, and by the same law it must diminish in proportion as they recede from each other.

62. Attraction, in technical language, is inversely as the squares of the distances between the two bodies. That is, in proportion as the square of the distance increases, in the same proportion attraction decreases, and so the contrary. Thus, if at the distance of 2 feet, the attraction be equal to 4 pounds, at the distance of 4 feet it will be only 1 pound; for the square of 2 is 4, and the square of 4 is 16, which is 4 times the square of 2. On the contrary, if the attraction at the distance of 6 feet be 3 pounds, at the distance of 2 feet it will be 9 times as much, or 27 pounds, because 36, the square of 6, is equal to 9 times 4, the square of 2.

63. The intensity of light is found to increase and diminish in the same proportion. Thus, if a board a foot square be placed at the distance of one foot from a candle, it will be found to hide the light from another board of two feet square, at the distance of two feet from the candle Now, a board of two feet square is just four times as large as one of one foot square, and therefore the light at double the distance being spread over four times the surface, has only one-fourth the intensity.

* For a further account of MAGNETISM and ELECTRICITY, see treatises on these branches of Natural Philosophy.

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48. Define attraction of gravitation, and its laws.
49. What of the laws of the intensity of light?

64. The gradual diminution of attraction, as the distance increases, is exemplified in the following table. In the upper line, the distance is expressed by progressive numbers; in the lower corresponding squares, the diminution of attraction is indicated by the common arithmetical fractions.

Distance	1	2	3	4	5	6	7	8	and so on.
Attraction	1	$\frac{1}{4}$	$\frac{1}{9}$	$\frac{1}{16}$	$\frac{1}{25}$	$\frac{1}{36}$	$\frac{1}{49}$	$\frac{1}{64}$	and so on.

It is here seen, that, at the distance of 8, the attractive force is diminished to a sixty-fourth part of what it was at 1.

65. The attractive force of matter is also in proportion to the numbers of the atoms of matter which a body contains; the attraction therefore does not proceed from the mere surface of a body, but from all the particles which individually compose it.

66. Some bodies of the same bulk contain a much greater quantity of matter than others: thus, a piece of lead contains about twelve times as much matter as a piece of cork of the same dimensions; and therefore a piece of lead of any given size, and a piece of cork twelve times as large, will attract each other equally.

67. The attractive power of any mass acts from the centre. At all equal distances from the centre, the attractive power is equal; for instance, in a body perfectly spherical, the attraction to the centre would be the same at all parts of the surface. The distance of the centre of a sphere from its surface is called the *semi-diameter* of that sphere—that is, the half of its thickness. At a point as far from the surface of a sphere as its semi-diameter, its attractive power is diminished to a fourth. At three distances, the attraction is a ninth; at four dis-

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50. Explain the table.
51. What of the number of atoms of a body?
52. What differences between bulk and quantity?
53. How does the centre of attraction vary?

tances, a sixteenth; and so on. When we wish, therefore, to ascertain the relative amount of the attraction which any mass of matter exercises over another, the rule is, to inquire how many semi-diameters of the one the other is distant from it, and then to multiply that number by itself. The result shows how many times the attraction at this distance is less than at the surface of the former. The moon, for instance, is distant 240,000 miles from the earth; or as much as 60 semi-diameters of the earth; 60 multiplied by 60 gives 3600; consequently, the attraction exercised by the earth upon the moon is a 3600th part of what it would exercise upon the same mass at its own surface.

68. If the earth were a perfectly spherical body, its attraction would be equal everywhere at the level of the sea. As the surface at the pole is thirteen miles nearer the centre than the surface at the equator, the attraction is stronger at the former than at the latter place; it gets proportionally weaker as we advance towards the equator, on account of the increase of distance from the centre. Hence, a mass of iron which is considered a pound weight in Britain, would be less than a pound on the coast of Guinea, and more than a pound in Greenland, for weight is only a result of attraction. If we ascend a mountain, the effect is the same as if we proceed towards the equator: we are always getting farther from the centre of attraction, and consequently weights become lighter. On the top of a hill four miles high, a ball of four thousand pounds' weight would be found to be two pounds lighter.

69. Pressure downwards, or weight, is in philosophical language termed GRAVITY, and under that head it is hereafter treated, in connection with the phenomena of falling bodies.

70. In the set of large spheres constituting the Solar System, the Sun is a central body of vast size, while the Planets are comparatively small bodies, revolving round him at different distances. If we take a stone in a sling, and whirl it round, the stone will have a tendency, in the

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54. By what rule is relative attraction found?
55. How illustrated with the moon?
56. Why does weight diminish toward the equator?

event of our slipping the string, to fly off in a straight line. This is called *Centrifugal Force*, that is, a force operating so as to cause a body to *fly from a centre.* When the planets received their first impulse, they had the same tendency as a stone in a sling to fly off in a straight line into space; in which case, they would never have come to a stop, till they fell under the attractive influence of some body of sufficient mass. But while impelled thus to fly off from the sun, they were also under the influence of his attraction, which, in this instance, is called *Centripetal Force*—that is a force impelling a mass to *seek or go to a centre.* At once impelled from the sun by their original motion, and drawn to him by his attraction, they took what may be called a *middle course*, and began to revolve round him at mean distances adapted to their rates of speed, and the force of the sun's attraction. The same laws caused the satellites to revolve at certain distances round the planets.

71. The attraction of bodies is mutual, and in proportion to the quantity of matter they contain. Therefore, any body, however small, exerts some degree of attraction upon the mass of the earth. Any body which comes immediately under our observation, is so small in comparison to the earth, that its attractive force is altogether unappreciable; but if the body were of great density, and of dimensions approaching to those of the earth, then we should see the earth rise to meet the body, or fall towards the body. The heavenly bodies, when they approach each other, are drawn out of the line of their paths, or orbits, by mutual attraction.

72. It is found by experiment, that a plumb-line suspended in the neighbourhood of a mountain, is sensibly attracted towards the mountain from the true vertical line.

73. The mutual attraction of matter is exemplified by the diminution of the weight of bodies, as we penetrate into the earth. At the depth of a mile, a body weighing

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57. Explain centrifugal and centripetal forces.
58. How is the revolution of the planets perpetuated?
59. How is the attraction of a mountain shown?
60. What change in gravity by nearing the centre of the

a pound would be found to be lighter than at the surface. This is in consequence of the attraction of the matter of the shell of the earth, which is exterior to the point, being nothing, in consequence of the attractions of its particles on this point counteracting each other; and hence the only efficient attraction on it arises merely from the smaller sphere below the point, and, therefore, the nearer the point is to the centre, the less is this internal sphere; and the less therefore is its attraction on the point.

74. Were we to proceed to the centre of the earth, we should there find that weight altogether ceased, because the attractive power would be equal on all sides. Were there a cavity at the earth's centre, the body would hang suspended in space.

75. The attraction of the earth's mass performs an important function, in binding the atmosphere, which is an elastic fluid, around the surface of our planet, and of causing the air to perforate every open crevice and pore in the superficial substances of the globe. The attractive force, in this respect, produces what is called *atmospheric pressure*, the air being pulled or pressed down by a force equivalent to about 15 lbs. on the square inch, at the level of the sea, and diminishes in proportion to the distance above that common level. The degree of atmospheric pressure at any given height is ascertained by an instrument called the *barometer*, which consists of a column of mercury in a tube, and by the pressure of the air upon which, the height above the level of the sea may be judged.*

76. Atmospheric pressure is, then, a result of attraction, and as such produces divers phenomena in nature. It is possible, by artificial means, to draw out the air from a confined vessel, as in the case of the air-pump and its receiver, so as to produce a *vacuum*, or almost perfect absence of air and its pressure; but it is not possible to diminish in any way the attraction of gravitation, which is a property inherent and indestructible in all matter.

* See treatise on PNEUMATICS.

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61. What effect has gravitation upon the air?
62. Name the average force of this pressure.
63. What instrument measures relative pressure?

77. Some bodies do not appear to be affected by attraction; for instance, smoke and vapours rise, instead of falling to the ground; in all such cases, however, attraction is present. Smoke consists chiefly of condensed vapour and minute particles of soot, and is carried upwards by the impulse of an ascending current of air, which is warmer, and therefore lighter, than the surrounding atmosphere. The sooty particles soon descend again, and the vaporous particles are commonly dissolved by the atmosphere, forming a transparent solution, and thus becoming invisible.

THE REPULSIVE QUALITY IN MATTER—HEAT.*

78. While attraction tends to unite and compress the particles of matter, there is another and equally universal principle, known in familiar language by the appellation of *Heat*, the tendency of which is to keep the particles of matter at a certain degree of expansion. Heat is often, in scientific works, named *caloric*, from the Latin word for heat.

79. Heat pervades all things, but some in greater degrees than others. Even ice has been found to contain a certain portion of heat. In fact, there is no such thing in nature as positive cold. The things which seem cold to us, are only under a low degree of heat.

80. The absolute nature of this universal principle is unknown. We only know it by its effects, and the sensations it produces. Some have conjectured that it is a fluid; others think it is a quality or affection of matter, resulting from electrical action. From its producing no sensible difference in the weight of any substance, it has been called an *imponderable body.*

* The operations and properties of Heat form a branch of knowledge sometimes called PYRONOMICS, a word signifying the Laws of Fire.

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64. How is gravitation proved without the air?
65. How is the ascent of smoke and vapour explained?
66. What principle in matter produces repulsion?
67. What of heat and of cold?
68. By what name is it designated?

81. When the heat of any particular substance, as ice, stone or wood, is not sensible to us, it is called latent (that is, concealed) heat. We may very readily detect its presence in a piece of wood or metal by rubbing or friction. If a button, for instance, be rubbed on a table, it will soon become too hot to be held by the fingers. In like manner, the axle of any carriage-wheel soon becomes hot, unless the friction is prevented by grease.

82. Heat, in its extreme form becomes fire. Thus, if an ungreased wheel be rapidly turned for a long time on its axle, so much heat will be excited that both wheel and axle will burst into a flame. The effects of powerful friction are known to savage nations, among whom it is common to produce fire by rubbing two sticks together.

83. Two pieces of flint struck together, or a flint struck hard upon a piece of iron, evolve sparks of fire. By such means, many important purposes are served; for instance, the discharge of fire-arms. Fire can also be evolved from the common atmosphere, by compressing a quantity of it suddenly in a tube, at the bottom of which a piece of tinder has been placed.

84. The evolution of heat by these means, and other circumstances, lead to the conclusion that heat is an element mixed up with the atoms of matter, which it serves to keep at a lesser or greater distance from each other. Thus, as we squeeze the pores of a sponge together, and disengage the liquid which they held in cohesion, so, when squeezing or rubbing a portion of matter, do we disengage the heat which it retained amongst its component atoms.

85. In all cases of the development of heat by pressure, hammering, and friction, the cause is the squeezing together of atoms which had been kept asunder by the latent fluid, and which fluid must, as a matter of necessity, come forth and make itself sensibly felt or seen.

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69. What is meant by latent heat? and how detected?
70. In what ways is artificial fire produced?
71. How is this explained?
72. What are the two great antagonist powers?
73. Of what use are these opposing agents?

REPULSIVE QUALITY OF HEAT.

86. Heat, then, is a principle of *Repulsion* in nature, and in this capacity its uses are as obvious as those of terrestrial gravitation, to which it apparently acts as a counterpoise. The force of attraction is so powerful, that unless for a counteracting principle of repulsion, all bodies would hasten into close contact; there would be no air, no water, no vegetable or animal life; all would be a uniform dead solid mass, and the earth itself might perhaps be reduced to a small portion of its present bulk.

MODIFYING QUALITY OF HEAT.

87. Heat, by pervading all things, modifies attraction, and, according to circumstances, regulates the density or solidity of bodies. Hence we possess in nature a beautiful variety of substances, some solid and hard, like stone and marble; others soft, or of the jelly form; a third class liquid, like water; and a fourth kind aeriform, or gaseous. Heat expands most bodies in proportion as it is increased in quantity, and they become solid in proportion as it is withdrawn. Water may thus be either expanded into the form of vapour or steam, or hardened into ice. When withdrawn, the process of *cooling* is said to take place; *cold* being simply a state of abstraction or comparative absence of heat.

CONDUCTION OF HEAT.

88. Heat is diffused or communicated by *conduction* and *radiation*. When it passes slowly from one portion of matter to another in contact with it, it is said to be conducted; and the process, in scientific language, is termed the *conduction of caloric*. Metals are the best conductors, then liquids, and, lastly, gases. Gold, silver, and copper, are the best conductors among solids: glass, bricks, and many stony substances, are very bad conductors; and

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74. How does heat modify bodies?
75. What variety in nature is thus explained?
76. Name the illustrations.
77. How is heat diffused? illustrate this.

porous spongy substances, as charcoal, hair, and fur, are the worst.

89. Clothing is generally made of bad conductors, that the heat of the body may not be conducted quickly to the surrounding air. Furnaces, where great heat is required, are built with porous bricks, which are very effectual in preventing the escape of heat, and do not readily communicate the fire to adjacent bodies.

RADIATION OF HEAT.

90. Heat is said to radiate, when it is emitted from a fire or from the rays of the sun, and affects the atmosphere or substances at a distance from its source. Radiant heat is absorbed when it falls upon bodies having painted or rough surfaces, such as are presented by bricks and other porous solids, by many kinds of stony matter, and numerous animal and vegetable substances, and makes them warmer as it is taken up. But brilliant and polished metallic surfaces absorb little heat; they reflect or turn it back again.

PRODUCTION OF HEAT.

91. Heat, as already mentioned, can be brought into action in most substances, by percussion and rubbing. It is also produced by the burning of certain inflammable substances, as coal and wood: and in this manner its chief purposes in domestic economy are effected. But the most remarkable source of heat is the sun; though whether this luminary is a burning mass, throwing off warmth like a common fire or red-hot ball, or produces the effect by some peculiar and unknown operation, is as yet uncertain.

92. Heat, besides being produced by the sun's rays, and by the friction and combustion of inanimate substances, is evolved by chemical action, a familiar example of which is observable in fermentation. It is by means of a natural chemical action in connection with the circulation of the

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78. Define and illustrate radiation.
79. Name the sources of heat.
80. Give examples of the chemical production of heat.

blood, that heat is resident and sustained in most living animals. A stoppage of the circulation of the blood, as every one knows, leads to an absence of animal heat, or a very considerable degree of coldness. On the contrary, quick circulation of the blood, and active muscular motion, as well as rubbing, produce heat. In these cases of motion and rubbing the heat seems to be in a great measure evolved by the momentary compression of the parts.

GENERAL DISTRIBUTION OF HEAT.

93. Heat is unequally distributed over the globe. At and near the equator, where the rays of the sun are sent in the greatest degree of directness, the greatest heat prevails. In the parts of the earth adjacent to the north and south poles, he transmits his rays so slantingly as to have little power; and there, accordingly, the air is seldom of a genial mildness. The higher we ascend in the air, the colder it becomes; the summits of very high mountains are always covered with snow. In penetrating into the body of the earth, after gaining a certain depth, the heat becomes greater in proportion as we descend. The interior of the globe is by many believed to be at a very elevated degree of heat, if not in a state of ignition. On the surface, great expanses of sea tend to equalize and temper the degrees of heat and cold in their neighbourhood, and great continents have the contrary effect.

TEMPERATURE—THE THERMOMETER.

94. The degrees of heat and cold in the atmosphere are called its temperature; and for ascertaining this correctly, with reference to a standard, a very ingenious instrument has been invented. This is called the *thermometer* (a word signifying heat measurer). It is a glass tube with a bulb at the bottom, into which mercury or quicksilver is put, with a scale of figures along the tube to mark the rising of the quicksilver. This instrument differs from

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81. What of the distribution of heat?
82. Name causes of its inequality.
83. What of temperature and its measurement?

the barometer, inasmuch as the quicksilver is sealed up close from the air. The atmospheric heat, however, affects the metallic fluid in the bulb, and, according to its warmth, causes it to expand and rise in the tube. The degree of temperature is indicated by the figures to which it ascends.

95. Our common thermometer has a graduation from No. 1, near the bulb, to 212, the degree of heat of boiling water. In the scale of figures, 32 is marked as the freezing point—that is to say, when the mercury is at the height of 32, *water* freezes; and the more it is below that point, the more intense is the frost. 55 is reckoned moderate heat, and 76 summer heat, in Great Britain. 98 is the heat of the blood in the average of living men.*

96. The rising of mercury in the tube of the thermometer offers a familiar example of the repulsive power of heat in expanding or dilating bodies. Common experience affords many such examples. A bar of iron is longer and thicker when hot than when it is cold. The iron rim of a wheel slips easily into its place when hot, and gripes or binds fast when it becomes cool. When heated from 32

* Different nations adopt different graduations in the scale of thermometers, which is a fertile source of error and confusion in estimating and comparing the statements of temperature made by scientific men in different countries. Where ever the English language prevails, the graduation of a person called Fahrenheit is generally preferred. By the Germans, Reaumur's is used; and the French now adopt what they term a centigrade thermometer. In the French centigrade thermometer, 0 is the freezing point, and 100 the boiling point; in Reaumur's thermometer, 0 is the freezing point, and 80 the boiling point. Each degree of Reaumur is equal to two and one-fourth of Fahrenheit. [Of course this rule can only be accurately applied by adding the difference of 32° in all comparisons between these two scales, the zero of Fahrenheit being 32° below the zero of Reaumur.] It was at one time imagined that the greatest cold could make the fluid in the thermometer fall only 32° below the freezing point, the place to which it then fell being *zero*, and therefore the notation commenced at that place. But much greater degrees of cold exist at different parts of our globe in winter, and may be produced artificially, so that the fluid in the stem of the thermometer often descends below that point, and is then said to be at so many degrees below zero. Thermometers in common use, however, are not made with a stem and indications below zero.

84. Describe this instrument.

to 212, air expands 3-8ths of its volume, alcohol 1-9th, water 1-22d, and hammered iron 1-273d. In these, and all similar instances, the expansion arises from the fluid of heat lodged among the atoms of matter pressing outwards on all sides according as it is excited.

REPULSIVE ENERGY—BOILING WATER.

97. The repulsive energy of heat is strikingly exemplified in the explosion of gunpowder. The particles of powder on being ignited, and assuming the form of air, are repelled with a force sufficient to lift immensely heavy bodies, and to project shot to a distance of several miles.

98. The repulsive energy of heat is also observable in the case of boiling water. When water is placed in a vessel on the fire, its particles become gradually heated. Those nearest the fire are heated first; being then of a lighter or more expanded nature, they hasten or are repelled to the surface, while the more cold and heavy particles sink downwards to the bottom, and are heated in turn. In this manner the process of heating proceeds, until all the particles are of a uniform temperature. There is a limit beyond which, in ordinary circumstances, they cannot be heated. This is when the water boils, and is signified by the bubbling motion of the fluid. Boiling takes place, as above mentioned, when the water reaches 212 degrees in the thermometer. Nature has designed that water should not become hotter by continued boiling, the application of heat after reaching this point being expended in transforming the liquid into vapour or steam. Hence it is not economical to boil any substance quickly which may only require exposure to a boiling temperature, as all the heat that may be consumed in producing vapour must cause an unnecessary expenditure of fuel.

99. The temperature of 212, at which water boils, is only reached when the ordinary atmospheric pressure is

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85. What examples of the repulsion of heat are cited?
86. Name the illustrations given of the force of repulsion.
87. How is this illustrated by boiling water?
88. Does water become hotter by continuing the boiling?

allowed to influence it. If the pressure be diminished or entirely removed by the air-pump, the water will boil or fly off in the vapour form at a much lower temperature. At the summit of high mountains, where the pressure of the atmosphere is less than at the common level of the surface of the earth, water boils at a lower temperature than 212. Thus, at the summit of Mount Blanc, the highest peak of the Alps, which is 15,666 feet above the level of the sea, it has been found that water boils at 187 degrees of the thermometer, or 25 degrees below the ordinary boiling point.

100. An interesting experiment may be performed with the view of exhibiting the boiling of water under the influence of a light pressure. Take a thin glass vessel, containing a quantity of water; hold it over a flame till it boils, and then briskly and securely cork it, and remove it from the flame so as to let it cool. It will at first cease to boil, but the vapour will soon be condensed so as to form a vacuum. By this means atmospheric pressure is partially removed, and the water again begins to boil. By pouring cold water on the vessel, the vacuum will become greater, and the boiling will become more violent. When at this stage in the process, pour boiling water on the vessel, and the vapour will again rise and fill the vacuum, so as to apply the pressure which was originally possessed, and the boiling will cease, but may be again commenced by a second application of cold water.

VAPORIFIC POINT—STEAM.

101. Different liquids reach the boiling or vaporific point at different degrees of temperature. Æther becomes vapour at 104 degrees, alcohol or spirits at 175, water at 212, and mercury at 692.

102. Steam is transparent, colourless, and invisible like the air. The white cloudy-looking matter which is emit-

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89. What becomes of the superfluous heat?
90. How is the boiling point of liquids affected by the atmospheric pressure? and how is this shown?
91. What simple experiment exhibits the differences?
92. What of the boiling point of liquids?
93. Describe steam, and the extent of the expansion.

ted in the form of vapour, is moisture produced by the partial condensation of the steam in the atmosphere. A cubic inch of water produces almost exactly a cubic foot of steam, or 1728 cubic inches. In proportion as we increase the heat which produces steam, and do not suffer it to escape, so do its repulsive properties become more apparent. It will burst the strongest vessels in which it may be generated or confined. When the force with which it expands is carefully regulated, so as to produce motion in machinery, it forms the most powerful engine which man has invented, namely, the steam-engine.

103. When steam is exposed to cold, it condenses into water, giving out all the heat by which it was produced; and hence the severe scald it produces when condensed on any part of the body.

104. Distillation consists in the production of vapour by heat; the spirituous particles of the liquid are carried off and condensed, by passing through a tube immersed in cold water.

SPONTANEOUS EVAPORATION.

105. Spontaneous evaporation is the term usually employed when vapour is produced slowly from a fluid, and without ebullition, as when water disappears from any moist surface. Evaporation, to a lesser or greater extent, is in constant exercise over the whole earth. The ocean, lakes, rivers, fields, are ever yielding up water in this invisible form to the atmosphere; and plants and vegetables, as well as living creatures, are also giving forth exhalations.

106. The atmosphere is thus a great receptacle for the moisture of the earth. When the temperature of the air is high, moisture in the atmosphere is not generally perceptible near the ground. But when the temperature is low, the air is felt to be damp or humid, in which condition it is unwholesome. Sometimes the humidity becomes

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94. Explain the effects and manner of condensing steam.
95. What of distillation?
96. Explain spontaneous evaporation, with examples.
97. What natural phenomena depend upon it?

so great, that the watery particles in the atmosphere are observable in the form of mist or fog. At night, when the plants lose their heat which they have contracted during the day, the moisture of the atmosphere is condensed upon them in the shape of dew, which, in very cold nights, becomes hoar-frost. When aqueous vapours are carried high into the atmosphere, or are formed there, they receive the name of clouds.

107. The invisible steam or vapour constantly arising from the pores in the skin of living animals, and exhaled in breath from the lungs, may be observed to condense into liquid on the insides of panes of glass in windows, and on the walls of apartments. This, however, only occurs when the walls are comparatively cold, or when the outer atmosphere affecting the glass is colder than the atmosphere within; and in proportion to the degree of external cold, so is the condensation and deposition of liquid greater.

FROST—FREEZING POINT.

108. When the temperature of the atmosphere falls below the freezing point, 32, which it does principally from the weakness of the sun's rays in winter, the phenomenon of frost, or freezing, ensues. Freezing is a process of congelation, or properly crystallization, produced by the withdrawal of heat, and by which water assumes the form of ice. When the temperature of the atmosphere rises above the freezing point, the ice melts, and is resolved into its original element.

109. When the temperature of the atmosphere is below the freezing point, the particles of water which are upheld in the clouds are frozen in their descent, and reach the earth in the form of flakes of snow. If this freezing take place after the particles have become united into rain-drops, we have hail instead of snow. When the descending flakes of snow come into a temperature above the freezing point as they approach the earth, they are apt to melt,

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98. What familiar example of condensed vapour is cited?
99 Explain freezing, snow, hail, sleet, &c.
100. Describe equilibrium with an example.

and, in such a case, fall in the shape of sleet, which is half-melted snow or hail.

EQUILIBRIUM OF HEAT AND COLD.

110. Heat has a constant tendency to preserve an equilibrium in all situations; and hence its diffusion through nature, and many of the ordinary phenomena in relation to temperature. When we touch a cold substance with our hand, a portion of the heat of the hand rushes into the substance, and leaves the hand so much deficient of its former heat. On the same principle, when we touch a substance which is warmer than the hand, some of the heat rushes into the hand, and renders it hot. When we pour a quantity of hot water into that which is cold, an equalization of the two temperatures immediately ensues. When the air at any particular place becomes heated or rarified, it ascends by virtue of its greater lightness, leaving a vacancy which the neighbouring air rushes in to supply. This is one of the chief causes of winds. The same principle is observable in the case of heated apartments. If the door of a heated room be thrown open, a current of cold air immediately rushes in to supply the deficiency in the rarified atmosphere.

111. Evaporation is always accompanied by the withdrawal of heat, or production of cold, when no heat is directly applied; the heat necessary for the production of the vapour is then derived or radiated from surrounding objects, as is mentioned above in the case of dew forming on plants.

112. Examples of spontaneous evaporation producing cold, are familiar to most persons. Bathe the temples with spirits, and the quick evaporation of the fluid will produce a feeling of considerable cold. A current of air, when not loaded with moisture, promotes evaporation; hence the rapidity with which a wet surface generally dries on a windy day.

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101. How does this explain winds?
102. What of evaporation, and how illustrated?

ARTIFICIAL FREEZING APPARATUS.

113. The circumstance of evaporation absorbing heat, and so producing cold, has led to the discovery of a plan by which water may be frozen into ice by simple artificial means, even in a warm room. The apparatus for performing the operation consists of an air-pump and its receiver. The receiver is a spacious glass vessel standing with its open end downwards on a flat dish, and which can be exhausted of air by the pump. In the dish a quantity of sulphuric acid is placed, and in the centre of the dish stands a cup or a tripod holding some water. The air being pumped from the receiver, the atmospheric pressure is removed from the water; evaporation rapidly ensues; the vapour as it rises is absorbed by the sulphuric acid, by which a vacuum is kept up; the temperature of the water sinks to the freezing point, and soon exhibits a cake or mass of ice. A powerful air-pump operating on several receivers will produce six pounds of ice in about an hour. Instead of sulphuric acid, highly toasted and dried oatmeal will answer the purpose of absorption.

GRADUAL ALTERATION OF TEMPERATURE.

114. In the great operations of nature, the withdrawal of heat to produce intense cold, and the application of heat to produce great warmth, ordinarily take place gradually. Thus, although water freezes at a temperature of 32, it is some time before frost is completely effectual in changing the aspect and condition of liquid bodies; and when the temperature rises a few degrees above 32, after a frost, the ice and snow which have been formed do not vanish immediately; indeed, ice will remain unthawed for several days after the temperature has risen some degrees above the freezing point. By this slow process, either in the absorption or evolution of heat, the animal and vegetable worlds are not liable to the injury which would ensue

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103. How is artificial freezing explained?
104. What of changes of temperature?

from instantaneous changes in the condition of their elementary fluids.

EXPANSION IN COOLING—CRYSTALLIZATION.

115. It has been observed that heat expands most bodies in proportion as it is increased in quantity. There are also instances in which substances expand in cooling as well as in heating. These substances are water, iron, antimony, bismuth, and many salts, in which solidification takes place by crystallization. In the cooling of melted lead, gold, or silver, the atoms solidify into a dense compact mass, leaving no visible pores between them. But when the atoms of water, melted iron, and other substances, solidify, they arrange themselves in the form of crystals, or minute needle-like parts shooting out in all directions, and leaving pores or vacant spaces in the mass. Thus, by the incorporation of pores, the bulk of the body is increased. Crystallization produces beautiful and regularly formed bodies, the forms being obviously the result of certain fixed laws, which, however, are not yet very well defined or understood.

POINT OF GREATEST DENSITY IN WATER.

116. The point of temperature at which water is most dense, is 40 degrees (or, according to some authors, $39\frac{1}{2}$). When the temperature is reduced below this point, the volume increases till it reach 32, when the liquid freezes. When the temperature is raised above 40, the volume increases till it reach the boiling point. Therefore, at any temperature below 40, as at 35, its volume is the same as for a temperature as many degrees above 40, that is, at 45.

117. When the surface of a body of water, whose temperature exceeds 40, is exposed to a lower temperature, the water at the surface, when it is reduced in the least degree, becomes heavier than the water beneath, and

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105. What substances expand on cooling?
106. What differences in the solidification of bodies?
107. How does certain temperature affect the density of water?

it consequently descends, its place being now occupied by a stratum of higher temperature, which is next cooled down and descends like the former; and this process continues till the temperature of the whole mass is reduced to 40 degrees. After the temperature has reached this point, the water at the surface becomes lighter than the subjacent mass, and it consequently remains stationary. If the temperature be lowered to or below 32, congelation takes place; and as ice, from its porosity, is lighter than water, it floats on the surface. From this circumstance, the process of congelation is retarded; for the latent heat or caloric of the water, which is in contact with the lower surface of the ice, evolved during congelation, instead of being quickly carried off by the atmosphere, as it would be were there no ice over it, must pass through the ice, which is a bad conductor of heat; and this circumstance consequently causes a delay in the process of congelation. Were it not for this evolution of latent caloric during congelation, and the buoyancy of ice, rivers would frequently be converted into one solid mass.

EFFECTS OF FROST.

118. The circumstance of water being increased in volume by congelation, explains the ordinary phenomenon of the bursting of water-pipes, and other similar occurrences, during frost. When a vessel of moderate strength is filled with water, its expansion, when it is converted into ice, by exposure to a freezing temperature, causes the vessel to burst. If the vessel is not brittle, but possessed of considerable tenacity, as a leaden water-pipe, the rupture will seldom be observed during the continuance of the frost while the water remains in a solid state, but it readily appears when thaw takes place, as the water is then forced out with a velocity corresponding to the vertical height of the column of water in the pipe. The

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108. Explain the phenomenon of freezing water.
109. What explains the buoyancy of ice?
110. What becomes of the latent heat?
111. Illustrate the expansion of water by freezing.

fissures of rocks, too, are widened by the freezing of the water which may happen to lodge in them before frost; and this process, therefore, is a powerful agent in the disintegration of rocks. Portions of steep banks, also, from a similar cause, tumble down after thaw; for the moisture in them expands when frozen, and thus rends them to pieces, which, however, during the frost, are bound together as by cement, and fall down whenever thaw dissolves the moisture. On the same principle may be explained the mouldering of soils which are turned over and exposed to the winter frosts. The moisture in the soil is frozen, which rends it into minute portions, which remain firmly united during frost, but crumble down whenever thaw takes place. It may also be frequently observed, that footpaths, especially when composed of a mixture of earth and gravel, are considerably raised during frost by the expansion of the frozen moisture in them, and they consequently become very soft after thaw. The husbandman is well acquainted with these effects, and takes advantage of them by turning up the soil, and thus exposing it to the influence of the winter frosts, which easily produce effects that would otherwise require a great amount of mechanical labour, skilfully applied, to accomplish.

119. To prove that water expands in freezing, place a phial full of water, and well corked, in a situation exposed to frost. In a short time the phial will be observed to be cracked all over by the expansion. If the cork be left out, it will be observed that an expansion has taken place upwards, and a mass of ice, resembling a cork in figure, has been projected above the mouth of the phial.

120. As ice thaws, it gives forth the air which it had incorporated in its pores; and this air, being of a higher temperature than the surrounding water, buoys up bubbles or air globules on the surface. Hence the froth on the surface and margins of lately frozen brooks.

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112. What effects upon the soil?
113. What simple experiment is cited?
114. Explain the results of a thaw.

SHRINKING OF BODIES BY HEAT.

121. Heat has a powerful effect in causing certain bodies to shrink and diminish in volume. This happens with those substances which do not liquify, such as wood and clay. The contraction arises from the heat carrying off the watery particles from the bodies, and thus allowing the constituent atoms to come more closely together. As wood becomes drier, its fibres are sometimes split asunder, so as to emit loud cracking noises, which, in the case of household furniture, are ascribed by the ignorant to supernatural causes.

IGNITION OF BODIES—FIRE.

122. Most bodies which are not convertible into vapour by the application of heat, as in the case of the wood just mentioned, are ignitible, and become luminous in the dark, when heated to 800 degrees, or about 1000 when heated in the day-light. This is observed equally in combustible solids, as charcoal, and in stony or other matters which do not flame. Combustible bodies, when in the state of luminous heat, are said to be on fire, or ignited.

123. From a state of simple ignition, heat may be augmented in intensity to a very high degree, till it exhibit, as is observable in furnaces, a white luminous appearance, at which height of temperature most metals and other substances are melted, and, if not removed and cooled, they are in a certain time destroyed. Fire is active in proportion to the combustibility of the substances on which it acts, and to the quantity of atmospheric air which is afforded to it. When fire is deprived of air, it speedily ceases, and is extinguished.

124. The principal effects produced by heat or caloric have now been mentioned; namely, repulsion of atoms or expansion, liquefaction, vaporization, evaporation, and ignition; also the effects produced by its withdrawal, namely,

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115. What bodies contract by heat, and why?
116. What of ignition, and at what temperature?
117. What of combustible bodies?

condensation, cold, freezing, and crystallization. A further consideration of the subject, particularly as regards combustion, belongs to CHEMISTRY. Under the heads PNEUMATICS and METEOROLOGY, some of the leading properties of heat will be recurred to, in connection with atmospheric phenomena.

ACCIDENTAL PROPERTIES OF MATTER.

125. While the beautiful and extensive variety of form in bodies—solid, liquid, gaseous and the different modifications of these—are to be traced to the operation of chiefly two great leading principles in nature, attraction and repulsion, the peculiar forms or characters which bodies assume from the influence of these or other causes, are usually described as the ACCIDENTAL PROPERTIES OF MATTER, for they depend on circumstances and are susceptible of variation. The following is a summary of these accidental properties:—*Density*, *Porosity* or *Rarity*, *Compressibility*, *Elasticity*, *Dilatation*, *Hardness*, *Brittleness*, *Malleability*, *Ductility*, and *Tenacity*.

DENSITY OF BODIES.

126. Density signifies closeness of texture, or compactness. Bodies are most dense when in the solid state, less dense when in the condition of liquids, and least dense of all when gaseous or aëriform. In this manner the degree of density is in agreement with the closeness of the atoms to each other. The density of bodies may generally be altered by artificial means, as is afterwards mentioned. The metals, in particular, may have the quality of density increased by hammering, by which their pores are made smaller, and their constituent particles are brought nearer to each other.

127. The more dense in substance that a body is, it is the more heavy or weighty. In speaking of the density of different solid and liquid bodies, the term *specific gravity*

118. Name the accidental properties of matter.
119. Define density, and its peculiarities.

is used to denote the comparison which is made. Thus, the specific gravity of a lump of lead is greater than an equal bulk of cork; or the specific gravity of water is greater than that of an equal quantity of spirituous fluid. For the sake of convenience, pure distilled water, at a temperature of 62 degrees, has been established as a standard by which to compare the specific gravity or relative weights of bodies. Water, as the standard, is thus said to be 1. When, therefore, any body, bulk for bulk, is double the specific gravity of water, it is called 2, and so on to 3 and 4 times, up to 22 times, which is the specific gravity of platinum, the heaviest known substance. In almost every case of comparison there are fractional parts, and these are usually written in figures, according to the following arrangement: Fractional parts are divided into tens, hundreds, thousands, and so on. If, in addition, to the figure expressing the main part of the specific gravity, there be one other figure, with a dot or point between them—thus 2·5—the additional figure signifies tenths, and the body is two times and five-tenths parts of a time more dense or heavy than water. If two figures occur—thus, 10·40—hundredths are signified, and the body is ten times and forty-hundredth parts of a time heavier than water. If there be three figures, thousandths of parts of a time are meant; if four figures, ten thousandth parts; and so on. Common air is sometimes taken as a standard with which to compare gases, being a more simple mode of comparing the relative weights of aërial substances. But all the solids and liquids are estimated with reference to water as the standard.

128. Any body of greater specific gravity than water, will sink on being thrown into water; but it will float on the surface, if its specific gravity be less than that of water. A body, such as a piece of wood, after floating a certain length of time on water, will imbibe such a quantity of liquid that its specific gravity will be gradually

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120. What is specific gravity?
121. How is this quality measured?
122. What of fractional parts?
123. By what standard are gases weighed?

increased, and in the course of time it may sink to the bottom.

129. The density of liquid bodies is liable to be altered by intermixture; for an increase or diminution of bulk often attends the combination of two different ingredients. Thus, a cubic inch of alcohol, a strong spirituous fluid, mixed with a cubic inch of water, will produce a measure less than two cubic inches; in mixing strong spirits with water, a diminution of about 4 gallons in the 100 takes place. The diminution in all such cases is occasioned by the mutual penetration of the particles of spirits and water; each liquid fills up the interstices in the other. An example of a combination of two bodies producing a body larger than the two bodies were individually, is seen in the case of incorporating tin with lead, by which an increase of bulk takes place.

130. Water is of a greater density or specific gravity than spirits; consequently, spirits are apt to float on the surface of water, unless the two liquids be well mixed, so as to produce a mutual incorporation of parts. A body which will float on water may sink in spirits. Although water has thus the greatest power of buoying up, it is in ordinary language called *weak;* and spirits, the lighter they are, are called the more *strong*. A knowledge of this relative power of buoying up has led to methods for discovering the strength of spirits. Small hollow glass beads, marked of different weights, are thrown into spirits; and the lighter, that is, the stronger, the fluid, the less weight of bead will be sustained. An instrument, consisting of a loaded hollow brass ball, and a rod with a graduated scale of figures rising from it, called a *hydrometer*, answers the same purpose. The ball, on being let into the fluid, sinks in proportion to the lightness of the spirits, and the degree of strength is indicated by the figure to which the liquid rises on the graduated scale. There is a certain point of strength called *proof*, below

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124. Wha varieties in the density of bodies occur on mixture?
125. How is the strength of spirits tested?
126. Describe a hydrometer, and its use.

which all liquids of a spirituous nature are legally prohibited.

131. In making calculations of the strength and specific gravity of spirits, by the above or any other means, attention must be paid to the degree of temperature of the fluid. Heat expands the liquor, and renders it lighter; all spirits are therefore more bulky, in proportion to their weight, in summer than in winter, and also *apparently* stronger, not really so. A cubic inch of brandy will weigh 10 grains less in summer than in winter; and what measures 33 gallons of spirits in summer, will measure only 32 in winter. Thus, if a person purchase spirits in winter, by measure only, and sell them again in summer, by measure only, he will profit to the extent of one gallon in 32. To effect sales of spirits on a principle of fairness, both to buyer and seller, the fluid must not only be measured, but its specific gravity established in connection with its degree of temperature. The standard heat of water, by which the specific gravity of liquids is compared, is, as already mentioned, 62 degrees, being the medium temperature all over the globe. If, therefore, spirits be above 62 in temperature, a corresponding deduction must be made from their estimated and apparent strength.

132. The relative specific gravity of solid bodies of precisely the same volume, is simply ascertained by weighing them in opposite scales of a balance, and the heavier of the two is the more dense, or has the greater specific gravity. This process, however, will not determine the true intrinsic value or character of any given substance. For instance, if a man were to bring a piece of metal to a goldsmith for sale, calling it a pound of gold, and the goldsmith put it in a balance and found that it really weighed a pound, there would be no certainty that the mass was wholly gold; it is possible that a portion of it might be lead, silver, copper, or any other inferior metal. How, then, should this difficulty be adjusted? All such questions, in relation to the specific gravity of bodies, are

127. What of proof spirits?
128. How are the effects of temperature manifest?
129. How is the relative specific gravity of bodies tested?

solved by having recourse to the *hydrostatic balance*, an instrument which acts upon a principle discovered by Archimedes, an ancient philosopher. The principle is, that the specific gravity of any solid may be determined by the bulk of water which a similar solid of the same weight displaces when plunged into it. The goldsmith above mentioned, by knowing, in the first place, how much water a pound of pure gold displaces, would try the metal brought to him by that standard; in other words, he would see whether it displaced the quantity of water proper for a pound of gold; if it displaced more than what was proper, then it contained alloy, was too bulky for a pound weight, and would be rejected accordingly.

POROSITY.

133. Porosity is the quality opposite to density, and means that the substance to which it is applied is porous; that is, full of small pores or empty spaces between the particles, and that the body is comparatively light. The instances of porosity are numerous in every department of the material world, but those which are connected with animal and vegetable bodies are the most remarkable. Bone is a tissue of pores or cells, and, when seen through a microscope, may be said to resemble a honeycomb. Wood is also a tissue of cells or tubes. If the end of a cylinder of straight wood be immersed in water, whilst the other is forcibly blown into, the air will be found to pass through the pores of the wood, and rise in bubbles through the water. When a gas is comparatively light, it is said to be *rare*, or to possess *rarity*.

COMPRESSIBILITY.

134. By compressibility is meant that quality in virtue of which a body allows its volume to be diminished, without the quantity or mass of matter being diminished. It arises, of course, from the the constituent particles being

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130. What of the hydrostatic balance ?
131. Define porosity with examples.

brought nearer to each other, and is effected in various ways. All bodies are less or more capable of being diminished in bulk, which is a conclusive proof of their porosity.

135. Liquids are less easily compressed than solid bodies; nevertheless they, to a small extent, yield, and go into smaller bulk by great pressure. The water at the bottom of the sea, by being pressed down by the superincumbent water, is more dense or compact than it would be at the surface.

136. Atmospheric air and gases are much more easily compressed than liquids, or even than many solids. Air may be compressed into a hundredth part of its ordinary volume. When at this state of compression, it has a great tendency to expand and burst the vessel in which it is confined. This is exemplified in the air-gun, in which a hundred pints of air are pressed into the size of one pint; and it is the force with which the confined and compressed air hastens to resume its former bulk, that causes the shot to be projected. When air is compressed to a much greater degree than the hundredth part of its ordinary bulk, the particles of matter of which it is composed collapse, and become so dense as to form a liquid of an oily nature; in which case, as in all other instances of compression, the heat which held the particles in suspension is forced out, and is felt to give warmth to the instrument or vessel in which the operation takes place.

ELASTICITY.

137. Some bodies have the power of resuming their former volume or shape when the force which diminished it is withdrawn. This quality is termed *elasticity.* Steel is one of the most elastic of metallic bodies, but its elasticity is not nearly so great as that of India-rubber, which, though twisted, drawn out, or compressed in different ways, always resumes its original form. The aëriform

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132. What of compressibility, and its universality?
133. What of this property in air, and its effects?
134. What of the extreme compression of air?
135. Define elasticity with examples.

fluids, such as atmospheric air, and the gases, are all exceedingly elastic; and so are liquids, such as water, but to a smaller extent.

DILATABILITY.

138. Dilatability is that quality of bodies by which they are enabled to be expanded or enlarged in their dimensions, without any addition being made to their substance.

HARDNESS.

139. Hardness is the quality which is the opposite of softness, and does not depend so much on the density of the substance, as the force with which the particles of a body cohere, or keep their places. For instance, glass is less dense than most of the metals, and it is so hard that it is capable of scratching them. Some of the metals are capable of being made either hard or soft. Steel, when heated to a white heat, and then suddenly cooled, as by immersion in water, becomes harder than glass; and when cooled slowly, it becomes soft and flexible.

BRITTLENESS.

140. Brittleness is that quality by which bodies are capable of being easily broken into irregular fragments; and it belongs chiefly to hard bodies. Iron, steel, brass, and copper, when heated and suddenly cooled, become brittle.

MALLEABILITY.

141. Malleability is the quality by which bodies are capable of being extended by hammering. Some of the malleable metals are gold, silver, copper, zinc at the temperature of boiling water, lead, iron, and some others. Some of the metals possess the opposite quality of brittle-

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136. Explain dilatability.
137. Upon what does hardness depend? examples.
138. Explain brittleness, with examples.

ness. Gold is the most malleable of all metals, and it may be hammered so thin as to be translucent, or permeable to light.

DUCTILITY.

142. By ductility is understood that property by which metals may be drawn into wire. The most malleable metals are not the most ductile. Tin and lead may be rolled into thin leaves, but cannot be drawn into wire. The most ductile metal is platina, which can be drawn into wire as fine as the threads of a cobweb.

TENACITY.

143. Tenacity is the quality by which bodies are not easily torn asunder. Steel is the most tenacious of all substances; a wire of this metal, the hundredth of an inch in diameter, will support a weight of 134 lbs.; while one of the same size of platina will sustain only 16 lbs., and one of lead only 2 lbs.

SUMMARY OF PROPERTIES.

We have now presented a definition of all the properties or qualities usually ascribed to matter, and, for the sake of fixing them in the mind of the pupil, we shall here shortly recapitulate them.

144. The essential properties of matter are Impenetrability, Extension, Figure, Divisibility, Inertia, and Attraction. Attraction is an essential property only when under the character of attraction of gravitation, or terrestrial attraction, as it is sometimes called. When exhibited under its supposed modifications in relation to cohesion, capillary attraction, chemistry, magnetism, and electricity, it is not an essential, but an accidental property, for it acts only according to circumstances. These modifications may be shortly styled Accidental Varieties of Attraction.

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139. What of malleability and ductility?
140. What of tenacity, with an example?
141. Recapitulate the summary.

145. The repulsive or expansive quality in matter is termed Heat, or Caloric.

146. The accidental properties of matter are Density, Porosity or Rarity, Compressibility, Elasticity, Dilatation, Hardness, Brittleness, Malleability, Ductility, and Tenacity.

MOTION AND FORCES—GENERAL EXPLANATIONS.

147. Motion is the changing of place, or the opposite of rest.

148. Matter, according to the definitions which have been given of its properties, is substance devoid of life and volition, and which is perfectly passive, or inert. It has been described as possessing the property of inertia, and in this respect it is said to possess an unwillingness or reluctance to move; but these phrases are only figurative, and are used for the purpose of conveying a forcible idea of the passiveness of its character. It is also, in consequence of this property of inertia, or passiveness to submit to any condition to which it is subjected, that a body, when once in motion, will continue to move continually with the same velocity and in the same direction, till it be disturbed by some external cause.

149. Any instance of rest which comes under our observation, is only rest in a *relative*, not an *absolute*, sense; that is, it is rest as relates to the earth, but not rest as relates to the universe; for though the stone which falls to the ground lies at rest on the earth, the earth is always in motion, and therefore the stone is no more at rest than the insect which sits upon a moving wheel is at rest. Hence, in speaking of bodies coming apparently to a state of rest, we must always recollect, that it is only relative, not positive or absolute rest. It is supposed that there is no such thing as absolute rest in creation. All the planets

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142. Define motion and matter.
143. What is ascribed to inertia?
144. What is said of absolute rest?

are in motion round the sun; the sun itself has a motion on its own axis; it is also believed by many astronomers that the sun has an onward or progressive motion in space, besides its rotary movement; and thus, perhaps, revolves round some distant centre, with all its planets in its train.

150. Common experience would lead to the conviction that rest is more natural for matter than motion; but this conviction is founded on a limited consideration of circumstances. The reason why we see ordinary moving bodies coming to a state of rest—such as a wheel stopping after having been whirled on its axle, a ball stopping after rolling on the ground, or an object falling to the earth after being thrown upwards—is, that they are sooner or later arrested in their progress by the earth's attraction or their own gravity, by the friction or rubbing against some other body, or by the opposition presented to them by the atmosphere. Except for these three prevailing causes of impediment and stoppage, all bodies once set in motion would go on moving for ever. Taking this expanded view of things, and dismissing the erroneous impressions arising from what is obvious only to our limited experience, we find that there is nothing more remarkable in perpetual motion than in perpetual rest.

151. It is only, however, in the great works of creation, or the heavenly bodies, that perpetual motion is observable. The planetary bodies are under the ever-acting impulses of centrifugal and centripetal forces, and are not impeded by friction, or by the atmosphere, for they move in space, or in a comparative vacuum. Many ingenious attempts have been made to produce perpetual motion on mechanical principles in terrestrial objects, but they have all necessarily failed, as no human effort can destroy gravity in bodies, or altogether prevent friction in movement.

152. In regard to bodies on the earth, of which a state

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145. Why does rest seem to be the natural state of matter?
146. What agencies obstruct motion?
147. What examples have we of perpetual motion?
148. Why have all experiments failed to discover perpetual motion in machinery?

of rest is the ordinary condition, motion is produced by certain agencies, or impelling causes, either belonging to the phenomena of nature or to art. The property of capillary attraction causes a motion in liquids under certain circumstances; the winds blow, and cause motion; rivers, in flowing down their channels, and the action of the tides, likewise produce motion; thus, there exist many natural causes of motion, which are taken advantage of by man in the economy of arts and manufactures. Motion in the animal economy is produced by a principle of life; but of the nature of this kind of motion mankind are ignorant, and nothing here requires to be said regarding it. The causes of motion which have to engage our attention are those which consist of *forces*, whether natural or artificial, and which forces have the property of impelling inanimate objects from a state of rest to a state of motion, of stopping them when in motion, or of altering the character of their motion. These forces are also called powers.

153. Motion, according to the mode in which the force acts, is susceptible of innumerable variations. According as the moving body is affected, it may move rapidly or slowly; proceed in a straight line, turn in a circle or curve; it may move with uniform or irregular speed, or be retarded or accelerated. The body may also move upon or in respect of another body which is also moving. Some of these peculiarities in motion will immediately engage our attention; meanwhile, it has to be explained, that, for the sake of convenience in language, and accuracy in the application of terms, certain words are used to define the nature of motion in bodies, and the forces affecting them.

154. Motion is said to be *common* to two or more bodies when they move in contact or together; or when, though not in contact, they are carried along in a similar manner, and with the same velocity; that is, when they have a motion in common, or participate in the same motion. Motion is said to be *absolute*, when a body actually moves

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149. What phenomena of motion are produced in nature?
150. What of the varieties of motion?
151. Define common motion.

from one point of space to another, or when it moves towards, or when it passes, another which is at rest. Therefore, setting aside the idea of the earth moving, we should say that a vessel moving on the sea has an absolute motion, while the land is fixed or stationary. Motion is said to be *relative*, when the motion of one moving body is considered in reference to that of another moving body. Thus, if two bodies move in the same direction, their relative motion is the difference of their motions; if they move in opposite directions, it is the sum of their separate motions.

155. When a force, applied to any material object, is resisted or counteracted, so that no motion ensues, it is called a *pressure;* and forces so counteracted are said to *balance* each other, or to be in *equilibrium.*

156. The degree of speed in the motion of bodies is called *velocity.* Velocity is measured by the space or distance passed over, with an invariable motion, and in a given time, as one second. Thus, if a body, in one second, with an invariable motion, pass over twenty feet, its velocity is said to be twenty feet per second.

157. When a motion is invariable, it is said to be *uniform;* if it be gradually increasing, it is said to be *accelerated;* and if it gradually decrease, it is said to be *retarded.* A force is said to be an *accelerating* or *retarding* force, according as it produces an accelerated or retarded motion.

158. Forces are either *instantaneous* or *continued.* The former is an impulse, like a stroke; the latter acts without intermission. When a continued force remains always of the same intensity, it is called a *constant* force. Other continued forces are said to be *variable.*

159. A body, in moving, possesses a force which is called its *momentum*, or *motal force.* Momentum is very different from velocity. A light body and a heavy body may move at the same velocity, but the momentum of the light body will be small in comparison with that of the

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152. Define relative and absolute motion.
153. Define pressure, balance, velocity, &c.
154. Name varieties in velocity?

heavy one. The light one, on coming to a state of rest, will perhaps fall harmlessly on the ground, while the other, by its momentum, will strike *forcibly* on the earth, or destroy any object which opposes it. Momentum is proportionate to the mass and velocity of bodies, and, by multiplying the weight by the number of feet moved over per second, we find that the momentum is the product. Thus, if a body of twelve ounces move with a velocity of twenty feet per second, its momentum is (twelve times twenty) two hundred and forty. In ordinary language, the term *impetus* is used to signify the violent tendency of a moving body to any point.

Before entering upon a consideration of motion as produced by ordinary forces, it will be appropriate to describe the effects produced upon bodies when simply falling—that is, moving downwards towards the earth, when the supports which upheld them are withdrawn.

THE PHENOMENA OF FALLING BODIES—WEIGHT.

160. Attraction, as already explained, is a force inherent in nature, by which particles and masses of matter are drawn towards each other. This force, it has also been stated, increases in proportion to the quantity of matter which the attracting body contains, and it also increases as the bodies approach each other.

161. Further, it has been mentioned that this powerful and subtile quality in matter is the cause of the falling or drawing of bodies downwards towards the earth, and thus produces what is termed *weight* or *gravity*. Gravity, then, is simply the tendency which any substance has to press downwards in obedience to the law of attraction, as exemplified in the phenomena of bodies falling from heights to the ground, when the supports which upheld them are removed.

162. All falling bodies tend directly towards the centre of the earth, in a straight line from the point where they are let fall. If, then, a body be let fall in any part of the

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155. What of momenum ?
156. Define gravity, and illustrate.

world, the line of its direction will be perpendicular to the earth's centre. Consequently, two bodies falling on opposite sides of the earth, fall towards each other.

163. Suppose any body to be disengaged from a height opposite to us, on the other side of the earth, its motion in respect to us would be upward, while the downward motion from where we stand, would be upward, in respect to those who stand opposite to us, on the other side of the earth.

164. In like manner, if the falling body be a quarter, instead of half the distance round the earth from us, its line of direction would be directly across, or sidewise, that is, at right angles with the lines already supposed.

165. It will be obvious, therefore, that what we call *up* and *down* are merely relative terms, and that what is down in respect to us, is up in respect to those who live on the opposite side of the globe. Consequently, *down* everywhere means towards the centre of the earth, and *up* signifies from the centre of the earth.

166. The velocity or rapidity of every falling body is uniformly accelerated, or increased, in its approach towards the earth, from whatever height it falls, if the resistance of the atmosphere be not reckoned.

167. If a rock be rolled from the summit of a steep mountain, its motion is at first slow and gentle, but as it proceeds downwards, it moves with perpetually increased velocity, seeming to gather fresh speed every moment, until its force is such that every obstacle is overcome; trees and rocks are dashed from its path, and its motion does not cease until it has rolled to a great distance on the plain.

168. The same principle of increased velocity in bodies, as they descend from a height, is illustrated by pouring treacle, honey, or any thick syrup, from an elevated vessel. The bulky stream, which is perhaps two inches in diameter where it leaves the vessel, is reduced to the size of a straw or a thread on reaching its destination; but

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157. What of the antipodes, and other positions?
158. How are we to understand *down* and *up*?
159. How is momentum and velocity increased, and why?

what it wants in bulk is made up in velocity, for the small thread-like stream at the bottom will fill a vessel just as soon as the large and slow moving stream at the outlet; the velocity is indeed so great, that the stream has not time to sink at once into the mass below, but falls in overlaying folds.

169. From the same principle, a person may leap from a chair without danger; but if he jump from the house-top, his velocity becomes so much increased, before he reaches the ground, as to endanger his life by the fall.

170. It is found by experiment, that the motion of a falling body is increased, or accelerated, in regular arithmetical progression. In other words, in every second of time during its descent, it acquires an additional rate of speed, the rate regularly increasing by the accumulation of the preceding additions.

171. It is ascertained that a dense or compact body, when falling freely, passes through a space of 16 feet 1 inch during the first second of time. Leaving out the odd inch for the sake of even numbers, we find that the space fallen through in a given time is determined by the following arithmetical computation.

172. Ascertain the number of seconds which a body occupies in falling. Take the square of that number (that is, the number multiplied by itself), and multiply the square by 16, which is the number of feet fallen during the first second, and the result is the amount of feet which the body altogether falls. For example, if a ball occupy 3 seconds in falling, we take the square of 3, which is 9; then we multiply 9 by 16, which gives 144 as the result, and that is the number of feet fallen. Again, if we find that the ball occupy 4 seconds in falling, we take the square of 4, which is 16, and multiply 16 by 16, the result is 256, which is the number of feet fallen. And so on, always following the same rule of computation.

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160. What examples are given?
161. In what proportion does velocity increase?
162. Give examples of the calculation

173. It is not always easy, by the above mode of calculation, to arrive at a correct result as to the height fallen by bodies, and all that can be expected is an approximation to a true result. This arises from bodies being of different bulks, and receiving different degrees of opposition from the atmosphere in their descent. It is a common supposition that large and heavy bodies fall more quickly than small and light ones. This opinion, which was maintained even by philosophers, until Galileo rectified the mistake, perhaps originates in the error of confounding *momentum* with *velocity*. Be this as it may, it is now an ascertained truth in science, that all bodies, of whatever density, fall with the same velocity. Thus, a ball containing a pound of lead falls with the same velocity as a ball containing an ounce. This equality in the rate of falling is, however, disturbed by the quality of figure and bulk of bodies. A solid ball of gold will fall more quickly than the same quantity of gold beat out into a thin leaf, because in the case of the leaf the resistance from the atmosphere on a large surface impedes the descent. Thus the atmosphere prevents bulky and porous substances from falling with the same velocity as those which are compact.

174. If the atmosphere were removed, all bodies, whether light or heavy, large or small, would descend with the same velocity. This fact is ascertained by experiments performed with the air-pump.

175. When a piece of coin, for instance a guinea, and a feather, are let fall at the same instant of time, from a hook which has held them at the top of the exhausted receiver of an air-pump, they are observed to fall at an equal rate, and to strike the bottom at the same moment. Hence it is demonstrated, that were it not for the resistance of the atmosphere, a bag full of feathers, and one of coins, would fall from a given height with the same velocity, and in the same space of time.

176. It has been stated that the attraction of gravitation

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163. What mistake results from confounding momentum with velocity?

164. How is it affected by bulk and figure, and why?

165. What of the air-pump?

increases in proportion to the quantity of matter which the attracting body contains. Thus, the mass of our planet, the earth, exerts a force of attraction which produces the phenomena of weight, and the falling of bodies with a certain velocity.

177. In consequence of the different size and density of the sun and planetary bodies, attraction is much stronger in some of them than others, and consequently the weight of bodies differs in each. On the surface of the sun, our pound weight would weigh upwards of 27 pounds, and a body would fall upon it 434 feet the first second. On the surface of Jupiter, our pound would weigh about 2 pounds 4 ounces. And on the surface of the moon, our pound would weigh only the fifth part of a pound.

178. As a body in descending to the earth receives increasing accessions to its velocity during every successive second, so when a body is projected upwards from the surface of the earth, its velocity decreases in the same proportion, till it comes to a state of momentary rest, when it instantly begins to descend with a gradually increasing velocity, which at any point in the descent is equal to its velocity at the same point when ascending. In this calculation, however we omit the influence of the atmosphere, which would cause the final velocity in the descent to be less than the original velocity with which the body was projected upwards.

THE CENTRE OF GRAVITY.

179. Terrestrial gravitation, as already explained, does not act on the mere surface of bodies, or according to their bulk, but is exerted in reference to all the particles or atoms individually which compose the mass of a body. As the earth is nearly of a spherical form, its attraction is the same nearly as if it proceeded entirely from the centre. On account of the great size of the earth, compared with that of any ordinary body at its surface, its attractive force

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166. How is gravitation increased by quantity of matter?
167. What of weight on the different planets?
168. What of the velocity of bodies thrown upward?

acts in straight lines, sensibly parallel, proceeding from the earth's centre. In the case of liquids, in which the atoms slightly cohere, the atoms have liberty to spread themselves over the earth, and to seek the lowest situation for repose. In the case of solids, a different operation is observable. In them, the particles of matter stick so closely together, that they are not at liberty to obey the law of gravitation individually, but rally, as it were, round a common centre, upon which the force of attraction may be considered to act for the general behoof. This centre is called the *centre of gravity*, the *centre of inertia*, or the *centre of parallel forces*.

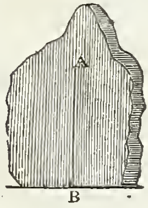
180. Every solid body or dense mass possesses a centre of gravity, which is the point upon or about which the body balances itself, and remains in a state of rest, or equilibrium, in any position.

181. The centre of gravity may be described as a point in solids which always seeks its lowest level, in the same manner that the lowest level is sought for by water; for it is only by propping up the body, that the centre of gravity is prevented from displaying the same mode of action.

182. The centre of gravity in round, square, or other regular shaped bodies, of uniform density in all their parts, is the centre of these bodies.

183. When a body is shaped irregularly, or when there are two or more bodies connected, the centre of gravity is the point about which they will balance each other.

Fig. 1.

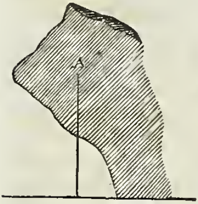


184. Any square or angular body which we may place on the ground, will remain stationary, or safely at rest, provided an ideal line, drawn from its centre of gravity, and passing to the ground in a direction perpendicular to the earth's surface, fall within its base, as in figure 1. A point below A is the centre of gravity; and from that point the line of direc-

169. What is meant by the centre of gravity, &c.?
170. Describe its variation in different bodies.

tion goes downward to B, which is within the edges of the base. An object of this form, and so placed, will stand.

Fig. 2.



185. If the line of direction from the centre of gravity fall without the outer edge of the base, as in figure 2, from A to B, then the object will not remain balanced on its base; it will fall over, and attain some position in which the line of direction falls within the boundary of the base on which it stands.

186. By keeping this simple principle in view, stability and safety will generally be secured in the erection of objects of art. such as houses, monumental edifices, spires, and obelisks, as well as in the lading of coaches, carts, and other vehicles, and the piling of timber or any kind of goods in heaps. In every instance, the base ought to be sufficiently broad to admit of the line of direction from the centre of gravity falling within it.

187. A small degree of experience seems to point out the propriety of erecting all kinds of structures with a base wide enough to secure stability; nevertheless, in opposition both to experience and the simple principles of science, we often find that stage-coaches are laden in such a manner that their centre of gravity is liable to too great a change of position, and that they are overturned, to the personal injury, and even loss of life, of the passengers. The error in these instances consists in raising the centre of gravity too high. At first, perhaps, the centre of gravity is so comparatively low, that, in the case of swaying to a side, the line of direction would fall within the edge of the wheel, and no danger would ensue; but it is common to go on piling masses of goods or luggage, or placing a number of passengers, on the roof of the vehicle, so that the centre of gravity becomes considerably elevated;

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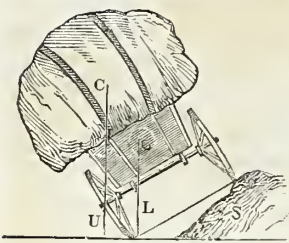
171. What of the line of direction?
172. What practical examples are cited?
173. Explain the upsetting of a vehicle.

Fig. 3.



so high, indeed, that when the carriage is swayed or jolts to one side, the line of direction is thrown beyond the wheel, and the vehicle will consequently fall over. In the annexed cut, figure 3, a loaded vehicle is represented crossing an inclined plane, or we may suppose that its wheel on one side has come in contact with a stone S, which has raised it above the level of the other wheel, so as to incline the body of the vehicle very considerably from the horizontal. The centre of gravity is represented in two different positions, a lower with the line of direction L C, and a higher with the line of direction U C. Had the vehicle not been high laden, the line of direction would have remained as L C, and as it falls within the wheel or base, the vehicle would have maintained its balance, but being now laden to a considerable height, the line has risen to about the place where it is marked descending from C to U, beyond the base; consequently the vehicle must overturn.

Fig 4.

188. Children who have not gained experience of the tendency which bodies have to be overturned when their centre of gravity is wrong placed, frequently receive falls and personal injuries by tumbling from pieces of furniture. In the annexed cut, figure 4, a little boy is represented standing on a chair, and leaning over its back. So long as the line of direction from A falls within the base at B, he is safe; but if he lean much farther over, and cause the line to fall beyond the base, to C, he must certainly tumble.

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174. Explain the drawing.
175. What other examples are cited?

189. Drunken men, who reel to and fro, are observed to have considerable difficulty in preserving their erect position. in consequence of the perpetual disturbance of their centre of gravity. Persons who feel themselves falling, instinctively throw out an arm, or try to lean in an opposite direction, so as to recover their balance. For the same reason, rope-dancers, in trying to balance themselves, use a pole loaded at each end with a ball of lead; and by inclining the pole in the direction opposite to that to which they feel themselves falling, they preserve their equilibrium. Some dexterous rope-dancers, by the use of their arms only, are able to maintain their balance.

190. There are instances in which bodies will not be overturned, although the line of direction falls considerably beyond the base. These exceptions to a common rule are observable in the case of rapidly and smoothly moving bodies, in which centrifugal force acts as a counterpoise to the weight of the body. A familiar example of this kind occurs in the case of skaters, in making their circular turns on the ice, in which they bend or lean greatly beyond the perpendicular position without falling. A notice of this peculiarity in moving bodies will engage our attention, under the head CENTRIFUGAL FORCE.

191. The tendency which leaning bodies have to fall, may also be counteracted in some measure by the cohesion of parts. Thus, there are many instances of walls, steeples, and towers, inclining sensibly from the vertical line, and yet, by the strength of the cement which binds them, they have stood for ages.

192. Whatever raises the centre of gravity, or narrows the base, allows the line of direction to pass more easily without it, and diminishes the stability. Hence the imprudence of rising up in carriages or boats, when in danger of being upset; and hence, as we have just mentioned, the danger of high-loading of vehicles. Lately an improvement has been effected in stage-coach building, by which a chief part of the load is placed as low as

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176. What exceptions are named?
177. What useful hints are given to avoid danger?

the axle of the wheels; and by this means the danger of overturning is almost entirely averted.

193. The centre of gravity of a body is not always in the substance of the body. Thus, the centre of gravity of a circular ring is in the centre of the circle; of an elliptic or oval ring, in the centre of the ellipse; and of a hollow cylindric tube, it is in the imaginary axis of the tube. In a drum, for instance, the centre of gravity is a point in the centre of the drum, where there is nothing but air.

194. When a circular object is placed on level ground, or a horizontal plane, it remains at rest on a point of its surface, because the line of direction from its centre, which is its centre of gravity, falls perpendicularly downwards to the point on which it is in contact with the earth and at rest; and because it could not possibly get its centre of gravity nearer the earth by changing its position.

195. When a similar circular object is placed on an inclined plane, it will not remain at rest, but roll over, because the line of direction from its centre of gravity falls perpendicularly downwards in front of the point on its surface which touches the plane. On this account it rolls over, as if it were seeking a spot on which it might have the line of direction from its centre of gravity passing through its point of contact with the earth. Hence a circular body continues rolling down an inclined plane till it find a level spot on which the line of direction passes through its point of rest.

196. In a bar of iron, six feet long, and of equal breadth and thickness, the centre of gravity is just three feet from each end, or exactly in the middle. If the bar be supported at this point, it will balance itself, because there are equal weights on both ends. This point, therefore, is the centre of gravity.

197. If a bar of iron be loaded at one end with a ball of a certain weight, then the centre of gravity will not be at the middle, but situated near the heavy end of the bar. But if we attach a ball of the same weight to both ends, the centre of gravity is again in the middle of the bar.

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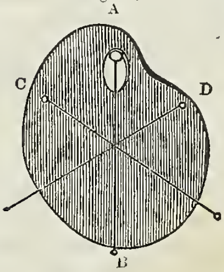
178. What variations in the centre of gravity?
179. Name the examples.

198. A remarkable illustration of the principles now detailed, is exhibited in the case of the earth and moon. The earth revolves round the sun, in consequence of a cause already explained, namely, the sun's attraction; but instead of the centre of the earth describing the oval or elliptic orbit round the sun, it is the centre of gravity of the earth and moon that describes it. We shall briefly explain the reason for this. The earth, in its course, is encumbered with the moon, a body about the 70th of its mass; in other words, the moon is like a small ball stuck at one end of a bar, having the earth or a larger ball at the other end—the bar between being the mutual attraction of the earth and moon. On this account, the centre of gravity of the earth and moon is at a point somewhere between the centres of the earth and moon. This point lies not far below the earth's surface. Therefore, if the earth were to fall towards the sun, it would be this point which would proceed most directly towards it.

199. In suspending an irregularly shaped body from different points successively, we may learn where the centre of gravity of the body is placed, by observing that the line of direction in each case passes through the same point, which point is the centre of gravity. For example, let a painter's palette, which is an irregularly shaped body, be suspended from the thumbhole, as in the annexed cut, figure 5, and the line of direction will necessarily be from A to B. Next suspend it from a point at D, and a new line of direction will be obtained, crossing the line A B. The place where the two lines intersect, is thus the centre of gravity. The point of suspension, on being removed to C, will give the same place of intersection in the original line of direction; and a similar result will follow any other change of the suspension point.

Fig. 5.



180 What is said of the earth and moon?
181. Explain the drawing.

200. In the various natural structures displayed in the animal and vegetable kingdoms, the centre of gravity is always so situated as to produce a just equilibrium and a harmony of parts. Every animal is properly balanced on its limbs, and every tree has a tendency to grow in a direction perpendicular to its base, whether it grow from a level or an inclined plane. Some animals are enabled to move in opposition to the law of gravity, as, for instance, flies creeping on the ceiling of an apartment; but in such cases, other powers in nature are exerted to preserve the secure footing of the animals.

201. Our perceptions and appreciations of the beautiful, both in nature and art, appear very much to depend on the objects we contemplate being constructed in reference to the preservation of their equilibrium or balance. An erect or properly balanced man, wall, steeple, and pillar, are more grateful to the sense of sight, than if they were leaning to a side. We feel as if an object in leaning were doing a violence to nature. Thus, the sight of lines and objects swayed from the perpendicular, in a ship agitated by the waves, disturbs all our preconceptions of what is consistent with nature, and powerfully assists in bewildering our senses, and rendering us sea-sick.

202. In consequence of this strong perception of the beautiful and pleasing, not to speak of the absolute utility, in perpendicularly erected structures, all artizans employed in building are anxious to preserve the true line of perpendicularity. For this purpose they have continual recourse to what they call a plumb-line; that is, a cord with a small ball of lead, or plummet, at its lower end, hung in a wooden frame; and this being applied to the edges of the structure as it proceeds, shows whether the true perpendicular line is preserved. Walls leaning from the erect position, are, from this useful instrument, said to be off the plumb-line.

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182. What is said of animal and vegetable structure?
183. What of beauty in nature and art?
184. How is sea-sickness accounted for in part?
185. How is perpendicular secured by builders?

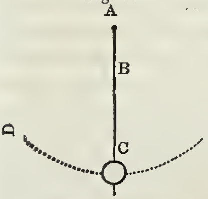
THE PENDULUM.

203. Gravity, which causes bodies to fall, also causes them to swing backwards and forwards, when suspended freely by a string or rod, from a point, and when once moved to a side, to give them an occasion of falling. A body suspended in this manner is called a Pendulum.

204. Pendulums usually consist of a rod or wire of metal, at the lower end of which a heavy piece or ball of brass or other metal is attached. When a pendulum swings, it is said to oscillate or vibrate ; and the path which its ball pursues in swinging, from its resemblance in figure to an inverted arch or bow, is called its arc.

205. In the accompanying cut, figure 6, a pendulum of the most common construction is represented. A is the axis or point of suspension. B is the rod. C is the ball, or a round flattish piece of metal, which is fastened to the rod by a screw behind, and by which screw it can be raised or lowered on the rod. D D is the path or arc which the ball traverses in swinging. When the pendulum is at rest, it hangs perpendicularly, as here represented, and the place which the ball is seen to occupy is called the point of rest.

Fig. 6.



206. The pendulum remains at rest till its ball is drawn aside to allow it an opportunity of swinging on its axis. Being raised to any height on one side, and set at liberty, the ball, by the force of gravity, has a tendency to fall to the ground, but being confined by the suspending rod, it is compelled to make a sweep to that point where it was formerly hanging at rest, immediately beneath the point of suspension. But it does not stop here ; it has acquired a velocity sufficient to carry it onward in an ascending course to nearly as high a point on the opposite side as that from which it was let fall. Of its own accord, it

186. Define a pendulum, and explain the drawing.
187. What of its motion, and why does it cease ?

again falls downwards in the same arc, and rises to near the point where it set off; and thus, of itself, continues to swing to and fro, or vibrate, for a certain length of time, till its force is expended, and it finally comes to a state of rest in its original dependent situation under the point of suspension.

207. At every sweep of the pendulum (when not meddled with, or assisted by any external force), the length of the path or arc traversed by the ball is in a small degree diminished. This arises from two causes—the obstruction offered by the atmosphere, and the friction on its axis or point of suspension. These causes, therefore, sooner or later, bring the pendulum to a state of rest, unless external force of some kind continues to be applied to urge it to sustain its action.

208. The ball of a pendulum in swinging, as has been mentioned, describes the figure of an arc. This arc is a certain portion of a circle. The extent of this portion depends on the force exerted in setting the pendulum in motion, or in drawing it aside to let it fall. A circle being divided by mathematicians into 360 degrees or parts, the ball may be made to swing over five, ten, twenty, or any other number of degrees under 180, which is half a circle. The extent of the arc traversed under ordinary circumstances, is from ten to twenty degrees.

209. When the ball of a pendulum traverses an arc not exceeding four or five degrees, it is observed to possess what is called the property of *isochronism*—that is, it passes over its point of rest always at the same interval of time (or very nearly the same interval), whether it traverse one, two, three, four, or five degrees; thus always accomplishing its excursion in precisely the same space of time. At first sight this seems doubtful; but a consideration of circumstances shows that it is perfectly correct. The cause of the phenomenon is, that the pendulum which goes over a greater extent of arc, has a greater speed than that which goes over a smaller extent. It should, however, be clearly understood, that the comparison as to

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188. What of isochronism?

lengths of time occupied in vibration, alluded to here, applies only to any given length of rod—that is to say, we must not compare the time occupied by a long rod with the time occupied by a short rod ; but, in every case, hold to only one rod, whatever be its length.

210. A pendulum with a long rod vibrates slower than one with a short rod. The time does not become longer, however, in exact proportion, as we extend the rod. The vibration it must always be recollected, is analogous to the falling bodies. The spaces fallen through by a body in 1, 2, 3, or 4 seconds, are not in proportion to 1, 2, 3, 4, and so on, but in the proportion of 1, 4, 9, 16, 25, and so on, or the squares of the time occupied in falling. In the case of pendulums, it is found that their lengths are as the squares of the times of vibration. Thus, if the times occupied by one vibration of two pendulums be 1 and 2 seconds respectively, the lengths of the pendulums will be as 1 and 4 ; so if the time of one vibration of several pendulums be as 1, 2, 3, 4, their lengths are as 1, 4, 9, and 16.

211. The vibrations of the pendulum being produced by terrestrial gravitation, it follows, as a natural result, that if the force of gravitation be weakened, so will the tendency of the ball of the pendulum to fall or swing be weakened. This result is distinctly observable in different parts of the earth. At the equator, the earth, as already mentioned, bulges out to a thickness of 26 miles on the diameter, or 13 miles from the surface to the centre ; and as the attraction of gravitation proceeds from the centre, the force of this attraction is consequently weaker at the surface at the equator than it is at the surface at the poles. At every part of the surface between the equator and poles, there is a proportionate increase of gravity. Besides the effect produced by the greater distance of the surface from the centre at the equator, centrifugal force, which is strongest at the equator, assists in weakening the attractive force at that place.

212. In consequence of these combined causes, a pen-

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189. How does the length of rod affect time ?
190. What difference occurs over the equator and why ?
191. By what rule is the length of the pendulum varied ?

dulum of a given length vibrates more slowly at the equator than at the poles. In proportion as we advance on the surface of the earth from the equator towards the poles, so does the pendulum swing or vibrate more quickly. In order, therefore, to preserve uniformity of speed in pendulums at different parts of the globe—that is, in order that they may all vibrate in one second, their length must be regulated according to the distance of the places from the equator. Thus, each degree of latitude has its own length of pendulum.

213. The uniform vibration of the pendulum has rendered it useful in regulating the motion of clocks for measuring time. In the common clock, a pendulum, connected with the wheel-work, and impelled by weights, or a spring, regulates the motions of the minute and hour hands on the dial-plate, by which the time of day is pointed out. If no pendulum were employed, the wheels would go very irregularly. The pendulum is regulated in length, so as to vibrate sixty times, each time being a second, in the space of a minute. At each vibration, it acts upon the tooth of a wheel, which turns the rest of the machinery. In order that the pendulum may vibrate neither quicker nor slower than sixty times a minute, in the latitude of London it must measure 39 inches and about the 7th of an inch from the point of suspension to the centre of oscillation. A pendulum at Edinburgh would require to be a small degree longer. The greatest possible nicety is required in the adjustment of the length; for a difference in extent amounting to the 1000th part of an inch, would cause an error of about one second in a day. Therefore, to make a pendulum go slower by one second a day, it must be lengthened by the 1000th part of an inch; and to make it go quicker, it must be shortened in the same proportion.

214. It is possible to cause short pendulums to regulate the movement of clocks the same as long pendulums; and this is done in cases where long pendulums would be inconvenient, or inelegant in appearance. This is accom-

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192. Describe the use of pendulums in clocks and their variety.

plished by shortening the pendulum to a fourth of its ordinary length, by which it beats or vibrates twice instead of once in a second. The wheel-work is constructed to suit this arrangement.

215. The pendulums of clocks being made of a rod of metal, they are liable to be extended by the heat of summer and shortened by the cold of winter; and by this means the uniformity of their motion is destroyed. Various contrivances have been adopted in order to compensate this effect on the motion of the clock, and pendulums constructed for this purpose are called *compensation* pendulums. The parts of the rods of these pendulums are so constructed and arranged that when one of them expands downwards, another at the same time expands upwards, by which any variation from temperature is greatly diminished.

216. In the moving mass of every pendulum, there is a point which is called the *centre of oscillation.* The centre of oscillation may be in the rod or in the ball, or even below the pendulum, according to circumstances. To understand this, it will be necessary to remember, that, if each particle of matter in the swinging body were at liberty to swing separately, those particles which are near the axis would swing more rapidly than those which are farther removed from it. Although the various component particles, from their intimate connection with each other, are not at liberty to obey this tendency, still the tendency exists. The nearer particles are retarded by those more distant, and those which are distant are accelerated by those which are nearer. There is thus a mutual exchange of influences among the particles of the swinging body. But there is a point or spot somewhere in the mass, where the mutual exchange is so completely equalized, that the influences or momenta neutralize each other, and the particle of matter situated at this point consequently swings as if unconnected with any other particle in the body. This point is the centre of oscillation.

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193. Whence the necessity of compensation pendulums?
194. What of the centre of oscillation?

217. The centre of oscillation in a pendulum is discoverable in the following manner. Take a common pendulum and set it a-swinging. Next, take a small ball of lead and suspend it by a fine thread from the same axis as that of the pendulum. This ball and thread form what is called a simple pendulum. It is simple, because the weight of the thread may be reckoned as nothing, and the ball vibrates with the smallest possible resistance or impediment; by which means it is well fitted for experiments. This simple pendulum is set a-swinging in front of the common pendulum, and its thread must be lengthened or shortened, as may be necessary, to cause the leaden ball to move at precisely the same pace or velocity as that of the common pendulum. Having rendered the two velocities exactly uniform, then stop both the pendulums, and the centre of the spot on the common pendulum, which the ball covers (supposing the ball to be perfectly circular), is the centre of oscillation.

218. It is to be noted, that the discovery of the centre of oscillation is not a matter of practical utility, as far as regards common or clock pendulums, but is interesting in a philosophical point of view, from the mechanical truths connected with it. For example, if we take a straight and uniformly thick bar of wood or metal, and suspend it in the character of a pendulum, we shall, by the means just pointed out, ascertain that its centre of oscillation is at a certain spot. If we then take the pendulum from its axis, reverse it, and suspend it from the spot indicated, we shall perceive, that, on being set in motion, it will again swing in agreement with the leaden ball and thread. The centre of oscillation and the point of suspension are thus said to be controvertible, without producing any change in the rate of vibration. How this result should follow, appears at first rather strange, but on consideration it will be found, that, by reversing the pendulum, there is a portion necessarily placed above the axis; wherefore, the speed which would ensue from the shortening of the

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195. How is this centre ascertained?
196. Of what importance is this experiment?

pendulum is counterbalanced by the retarding influence of the portion placed above the axis.

THE LAWS OF MOTION.

219. Motion, as already mentioned, is the changing of place or the opposite of rest.*

220. According to the general explanations which have been given, it appears that motion in bodies is as natural as rest, and that matter passively submits to remain in either of these states in which it may be placed, provided no external force or obstacle interfere to cause an alteration of condition.

221. These and other fundamental laws of nature, in relation to rest and motion of matter, are laid down by Sir Isaac Newton in the following three propositions :—

1st, Every body must persevere in its state of rest, or of uniform motion in a straight line, unless it be compelled to change that state by forces impressed upon it.

2d, Every change of motion must be proportional to the impressed force, and must be in the direction of that straight line in which the force is impressed.

3d, Action must always be equal and contrary to reaction : or the actions of two bodies upon each other must be equal, and their directions must be opposite.

222. These propositions we shall treat separately. In the first of the series there are three points requiring consideration, namely, the permanency, the uniformity, and the straight line of direction, of motion in bodies.

UNIFORM MOTION IN A STRAIGHT LINE.

223. As was formerly observed, it is impossible to show either permanency or uniformity of motion in bodies

* In scientific language, the nature and laws of motion form a branch of knowledge called DYNAMICS (a word signifying power or force); while the principles of forces in equilibrium are classed under the term STATICS (a word signifying to stand or be at rest).

197. Name Newton's three propositions.
198. What considerations are important in the first?
199. Where are the laws of motion most clearly illustrated?
200. Define Dynamics and Statics.

upon or near the earth; for all moving bodies are sooner or later brought to a state of rest by the force of attraction, friction, and the opposition of the atmosphere. It is only, therefore, in the case of the great works of nature or planetary bodies, that the laws of motion are most clearly and fully illustrated. In them, motion is uniform and permanent. The earth, for example, moves at the present moment with the same regularity, the same placid steadiness, that it did thousands of years ago. On account of this regularity and permanency of motion, astronomers are able to calculate eclipses of the sun, moon, or other heavenly bodies, at any distance of time. They can foretell, to an instant of time, at what part of their orbits the earth or moon will be a thousand years hence. The motions of the planetary bodies also afford a standard wherewith to reckon the course of time.* We call the space of time occupied by a revolution of the earth in its orbit round the sun, a year—that of a revolution of the earth on its axis, a day—that of a revolution of the moon round the earth, a month; and these periods we divide into weeks, hours, minutes, and seconds. Thus, time is sectioned and computed with unerring accuracy. The inhabitants of the different planets, in all likelihood, take advantage of the same means of reckoning their time, each planet, however, having its own peculiar length of year and day, according to the period occupied in its revolution round the sun or on its axis. In Jupiter, the year is nearly 12 of our years, and the length of the day nearly 10 hours. In Mars, the year is 1 of our years and 321 days, and the day 24 hours and 39 minutes. In Venus,

* The motions of the planetary bodies are here spoken of as being uniform or regular; this is not strictly correct. When we come to treat of Astronomy, it will be shown that there are certain irregularities in the motions of the planets, caused by their action on each other; but as these irregularities are the subject of calculation, and do not disturb the harmonious permanency of motion in the system of the universe, it has been thought unnecessary to advert to them in the above popular definition.

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201. How is time reckoned by the motions of the planets?
202. What of motion in a straight line?

the year is only 224 of our days, and the day 23 hours and 21 minutes.

224. The tendency of a body to move in a straight-line from the point whence it set out, is as much a property of matter as the uniformity of motion. If we conceive the idea of a body impelled into a state of motion by any given force, and at the same time conceive the idea that there is no obstacle to interrupt it, no attractive force to bend it aside, we shall then fully understand that a moving body must, as a matter of necessity, from its property of inertia, proceed in a straight line of direction—it must go on an even path for ever.

CENTRIFUGAL FORCE AND CIRCULAR MOTION.

225. Bodies in flying round a centre have a tendency to proceed in a straight line, and this principle of motion, as already mentioned, is termed *centrifugal force.* Examples of this tendency are very familiar to our observation. When we whirl rapidly a sling with a stone in it, and suddenly allow the stone to fly off, it proceeds at first in a straight line, but is gradually pulled to the earth by attraction. In turning a circular grinding-stone rapidly with water in contact with it, we perceive a rim of water first rising on the stone and next flying off; and the more rapidly we turn the stone, so does the water fly off with the greater force. In grinding corn by two rapidly turning stones playing on each other, the grain poured in at an opening at the centre is quickly shuffled towards the edges of the stones and expelled in the condition of meal or flour. If we put some water in a vessel, and rapidly turn it in one direction, we shall find that the water endeavours to escape, and rises up to the edges of the vessel, leaving a deep hollow in the middle. The tendency to fly off from a centre is made use of in the manufacture of pottery: Soft clay being placed on a revolving wheel, it quickly spreads towards the circumference of the machine, and is guided or moulded by the hand of the potter into the

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203. What of centrifugal force? examples.
204. What manufactures are on this principle?

required form. In forming common crown or window glass, advantage is also taken of the principle of centrifugal force. A thick round mass of glass, softened by heat and fixed at the middle on an iron rod, being made to turn rapidly round first in one direction, and then in the opposite, and continuing this alternating rotary motion till the glass becomes cool, is found to spread out into a large, thin, circular plate. From this plate, square panes of glass are afterwards cut.

226. Equestrians, in performing their feats of horsemanship, always incline their bodies inwards when standing on a horse which is running round a circle. Centrifugal force having a tendency to impel them outwards, is thus counteracted by the inward leaning, and forms a species of support to their overhanging bodies. A horse running in a circle, or quickly turning a corner, naturally adopts the same counteracting posture, and leans inwards. A skater, in moving in a circular or curvilinear path on smooth ice, also leans inwards, so much so, that if he were to stand still in this posture, he would inevitably fall on his side ; but centrifugal force, which has a tendency to impel his body outwards from the curve, or in a straight line of motion, sustains him, as it does the equestrian, and he therefore moves gracefully and safely in the circular path which his fancy directs. In this and other instances, we find the force of gravity overcome by centrifugal force. It is in obedience to this principle, that the earth bulges out to the thickness of 26 miles upon the circumference at the equator, where the whirling motion is most rapid.

227. Thus centrifugal force is the tendency to fly off in a straight line, or at a tangent, from motion round a centre; and the power which prevents bodies from flying off, and draws them towards a centre, is, as already mentioned, called *centripetal*, or *centre-seeking* force. All bodies moving in circles are constantly acted upon by these opposite forces, as may be exemplified by the annexed cut, fig. 7. A is a point to which a string with a ball at the end

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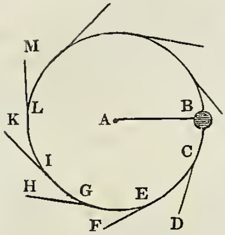
205. Name the other illustrations here cited.
206. What of centripetal force ?

Fig. 7.



of it, B, is attached. On forcing the ball B into motion, it will describe a circle round the point A, in which case the string is the centripetal force. The ball in whirling, however, having a continual tendency to fly off, if it be disengaged from the string at C, will go in a straight line C D; if at E, it will go in the line E F; if at G, in the line G H; and so on, at every point in the circle.

228. The mutual action of centrifugal and centripetal forces, in the case of circular motion, proceeds according to a certain ratio. If the mass of the revolving body be increased, its distance from the centre and velocity remaining the same, its centrifugal force will be increased in the same proportion. If the distance from the centre be increased, while the mass and the time of revolution remain the same, the centrifugal force will also be increased in the same proportion. If the number of revolutions performed in a given time be twice as many, the distance and mass being unchanged, the centrifugal force will be four times as great; if three times as many, the force will be nine times as great; if four times as many, it will be sixteen times as great; and so on in the same proportion. The masses of the planets, and their distances from the sun, being various, the forces which affect them are also similarly varied.

229. The line round which a body performs a motion of rotation, is called an *axis.* This axis may be only imaginary, like that of the earth; or real, as the axle of a wheel. The body may revolve about two projecting pins or pivots resting in sockets, in which case its axis is a straight line joining the pivots; or it may turn on a cylindrical rod of small diameter, passing through the body, like a wheel on its axle. It is evident that every point of the body,

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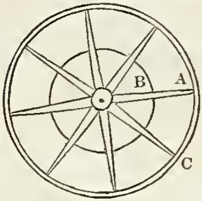
207. Explain the diagram.
208. What of the mutual action of these two forces?
209. What of the axis?

during its revolution, will describe a circle, the centre of which is a point in the axis of the body.

Fig. 8.



230. In the turning of a wheel on its axis, that part which is at the greatest distance from the centre has the greatest velocity; and at this extremity of the circumference, the centrifugal force is greatest. For example, in the representation of a wheel with arms radiating from a centre, (figure 8,) the velocity is greater at the extremity of the arm at A, than it is at B, half the distance from the centre. But the point B goes round as often as the point A, having a smaller circle to traverse.

231. In this manner, the velocity of revolving bodies must always, as a matter of necessity, increase in proportion to the distance from the centre of motion. Hence a comparatively small centrifugal force near the centre, is prodigiously increased towards the circumference. By increasing the force, and adding to the velocity of a revolving body, the centrifugal force becomes so great that it will in some cases overcome the cohesiveness in the material of the body, and cause it to break and fly off in pieces. When grinding-stones are thus whirled with great rapidity, they are apt to be destroyed, flying in pieces to the extreme danger of those who are using them.

232. The power of centrifugal force in rapidly whirling bodies, may be rendered so great as to overcome the force of gravity. In whirling a sling with a stone in it, the stone does not fall out of its place in the sling. The following is a more striking example :—Place a jug of water on the inside of the rim of a wheel a few feet in diameter; then, beginning gradually, set the wheel in rapid motion. and it will be observed that the jug retains its place, whirling round in a perfectly stable manner, and that even the water in it is not spilled. Thus, gravity, or the tendency to fall downwards, is overcome by centrifugal

210. Explain the diagram.
211. What of increased velocity?

force. If the jug were placed in a situation in the wheel, near the centre of motion, where the centrifugal force is weak, it would at once fall to the ground.

233. When the axis of a revolving body is imaginary, it is sometimes in motion itself, like the axis of the earth. In most cases of rotary motion, the axis is immovable, and the motion always in one direction, as the wheels of watches, clocks, and machinery; and in some cases the motion is alternating or reciprocating, as the vibrations of a pendulum, the oscillations of the balance-wheel of a watch or chronometer, or the working-beams of steam-engines; in which cases the motion continues in one direction only for a short period, and is then reversed. This alternating motion is called *oscillation* or *vibration*.

234. When a body, which is quiescent and free, as a ball lying on a perfectly smooth plane, is acted on by an instantaneous force, and in the direction of its centre of gravity, the body will be impelled with a uniform motion in the direction of the stroke, having only this *motion of translation*, as it is called, without any *motion of rotation*. If the impulse given to the body be not in the direction of its centre of gravity, it will still receive the same motion of translation, but it will also have communicated to it a motion of rotation about its centre of gravity. In this case, each of the two motions will be exactly the same as if the other did not exist.; that is, the progressive motion is the same as if the direction of the impulse passed through the centre of gravity, and the motion of rotation is just what would be produced by the same impulse, if the body had a fixed axis through its centre of gravity, and about which it whirled.

235. There is a point at a certain distance from the axis of a revolving body, at which, if all its matter were concentrated, it would give exactly the same resistance to the communication of rotary motion, as the whole body itself does, supposing that in both cases the same impulse is given, and at the same distance from the axis. This

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212. Will this force overcome gravity?
213. Describe oscillation and other forms of rotary motion.
214. What is a motion of translation, and how complicated?

point is called the *centre of gyration*, and its distance from the axis is called the *radius of gyration*. This centre of gyration is analagous to the centre of oscillation in vibrating bodies. The product of the number representing the mass or weight of a body into that denoting the square of the length of this radius, is called the *moment of inertia*. For example, let a wheel be 10 pounds in weight, and its radius of gyration 2 feet, the square of which 2 is 4; then multiply 10 by 4, and 40 is given as the moment of inertia. The word *moment*, used in this sense, is a contraction of *momentum*, a term which in this respect is now disused, in order to prevent its being confounded with momentum in ordinary moving bodies.

236. If the parts of a body be symmetrically distributed around an axis of rotation, that is, if equal portions of the body be placed at equal distances from it, and in directly opposite directions, the opposing centrifugal forces will balance each other, and there will be no pressure on the axis, and the body would revolve permanently about it. Thus, a sphere of uniform density would revolve permanently about any of its diameters. A cylinder of uniform density would also revolve permanently about its axis. If the revolving body be not uniform, or fairly balanced on its imaginary axis, it will possess an irregular or hobbling motion, and come sooner to a state of rest by friction than would be the case if it were of regular density, or properly balanced. Examples of this are very familiar.

LAWS OF PROJECTILES.

237. Bodies, on being projected by any impulsive forces, are called *projectiles*, and are observed to pursue a curvilinear or bent line of direction in their motion. The bending from the straight line is produced by the force of gravity, and "the change is proportional to the impressed force."

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215. Explain the centre and radius of gyration.
216. What of the moment of inertia?
217. What of the uniformity of a revolving body?
218. What of projectiles?

238. A ball projected from a cannon, a stone thrown by the hand, and water spouted from a confined vessel, furnish familiar examples of curvilinear motion.

239. It is a remarkable law of motion, that, whether the force which projects a body be great or small, the body, if thrown horizontally, will reach the surface of the earth from the same height, in the same space of time, not calculating resistance of the air. For example, if two guns are fired from the same spot at the same instant, and in a horizontal direction, one of the balls falling half a mile, and the other a mile distant, it will be found that the ball which proceeds the greatest distance takes precisely the same time to reach the ground which the other does.

240. The time of flight, as it is called, of two balls, will be the same in whatever directions and with whatever velocities they are fired, provided they reach the same height.

241. The reason for the same length of time being occupied in falling by both balls, is, that they are both carried downward at the same rate by gravity. Hence, a ball dropped perpendicularly from the top of a high tower, does not reach the ground sooner than a ball shot from the same height to the distance of one or more miles in a horizontal direction.

242. In projecting bodies through the atmosphere, great advantage, in point of distance, is gained by impelling them from heights, because a ball thrown from a high situation to a lower, reckoning its whole course, is more aided than retarded by gravity. When the ball is projected from a lower situation to a higher, it is in the first place retarded by gravity in its ascent, and the acceleration afterwards by gravity being less than this previous retardation, it consequently does not go so far, or has not such a wide range, as if projected from a height. Skilful generals, in bombarding towns at a safe distance, take advantage of this law of projectiles.

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219. Give examples of curvilinear direction.
220. What law of motion is shown by cannon balls?
221. Why this similarity of time?

We are now prepared for the consideration of one of the most important principles in Dynamics, namely, the law of motion which governs a body after receiving a projectile impulse.

243. A projectile exhibits a composition of motion, namely, a horizontal motion forward, when thrown in that direction, produced by the impressed force ; and a descending motion, produced by gravity, or the earth's attraction. These two motions are unequal; they are not at the same velocity. The horizontal motion is uniform, while the descending motion, according to the law of gravitation in relation to falling bodies (see 170), is accelerated. The consequence is, that the projectile, as already mentioned, pursues a curved line of direction, the convex side of the curve being uppermost.

244. The degree of curvature of the line of motion depends on the amount of the original projectile force. The law is, the greater the projectile force, or the greater the original velocity of the object, so is the sweep of the curve proportionally greater.

245. Let us suppose that the projectile force is sufficient to carry a cannon ball ten miles; this will give a very wide curve, allowing that the ball is shot from a lofty situation. But let us add to the projectile force, and send the ball double the distance, and the curve is now exceedingly wide. If we in this manner go on adding to the projectile force, we at length give the ball such a motal force that it will go quite round the world; instead of describing portions of curves, it will describe a whole circle.

246. This conducts us to a most extensive result. We have at once placed before us a reason why the planetary bodies should have assumed curvilinear paths in relation to the sun. The original projectile force which they received, in connection with the force of gravitation, has obliged them to pursue curved lines in their motion; and once being disengaged, they have, by a balance of centri-

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222. What law of projectiles is useful in military operations?
223. What of the compound motion of projectiles?
224. How is this law of projectiles illustrated?
225. What important bearing has this upon astronomy?

fugal and centripetal forces, continued to travel in circular, or, properly speaking, elliptical orbits—the ellipticity being caused by a want of exact uniformity between the forces which affect them.

A calculation of these forces belongs properly to Mathematics, and will engage our attention when treating of ASTRONOMY.

ACTION AND REACTION.

We proceed to a consideration of the first cause in the third proposition of Newton—"Action must always be equal and contrary to reaction."

247. Action is the impression of force. A blow is action; pressure is action. Reaction is resistance; but the word resistance does not fully convey the meaning of reaction, which properly signifies the action of striking or pressing back, even although the body struck or pressed upon do not move.

248. When a man strikes a hammer upon a fixed stone, the stone strikes the hammer at the moment of contact as much as the hammer strikes it. But if the stone be not fixed, and be liable to be easily upset, then its reaction is less, and it acquires a momentum. When a boy throws his ball against the wall of a house, the wall reacts on the ball, and causes it to rebound; but if the boy throw his ball at a pane of glass with the same force, the glass, having the power to resist only a portion of the force, gives way before it. In this case, if we suppose the ball to possess the action or force of 4, and the glass to possess the reaction of 2, the ball in passing through the glass loses 2 in its force, and retains the remaining 2. If it then came against another pane possessing a reactive power of 2, it would not break the glass, and, its force being now spent, it would fall to the ground. Thus, "action and reaction are equal."

249. A story is told of a person who, from his knowledge of the law of action and reaction, betted that he

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226. Define action and reaction, and their relation.
227. What illustrations are cited?
228. What examples in proof are given?

would lie down on the ground and allow an anvil to be placed upon his breast, and that any one might strike the anvil with as much force as he was pleased to exert. In this case, the person who made the offer was quite safe, provided he could support the weight of the anvil; for if a blow were given with the utmost force by a comparatively light body, as a hammer, though it would communicate nearly double its momentum to the anvil, yet the anvil, being so heavy, would acquire so small a velocity that the shock given to the person would be insensible. Were a freestone of the same weight as the anvil used, it would give a still less shock, for the action and reaction of perfectly elastic bodies are twice as great as that of inelastic bodies. Iron has more elasticity than stone.

250. It is by reaction acting contrary or in opposition to action, that the movements of living objects are rendered effectual. When we walk on the ground, the ground resists the pressure, and we feel ourselves steadied. A bird in flying pushes itself onward by the flapping of its wings against the partially resisting medium of the atmosphere. The partially resisting force of water, in the same manner, allows a fish to propel itself by its tail and fins. A sailor in rowing a boat causes the oars to push against the water, and, the water partially resisting the force, motion is communicated to the boat. In pushing a boat from the shore, the firm ground has such a power of reaction, that we are able to give the boat much greater momentum than if we pushed only against water. If we go into the boat, and try to move it, by merely pressing against some part of its fabric, no motion whatever is produced, for the action and reaction are equal. The whole force employed must be rendered greater than the reaction, otherwise no motion can be communicated to the body.

251. When two bodies come into collision with each other, as in case of two bodies moving in a straight line, but opposite course to each other, the law of action and reaction being equal, will not be clearly illustrated, unless the collision be in the direction of the centre of gravity or

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229. What of the movements of living objects?

inertia of the two—in common language, unless the blow be *fair*. The centre of gravity, in cases of this kind, is called the *centre of action*, or *percussion*. For example, when we strike a ball with a club, fairly against its side opposite to its centre of gravity, it is impelled to a considerable distance; but if we strike it above this central point, a part of the force is expended in vain, or lost, and the ball moves but a comparatively short distance. Experience has demonstrated that the centre of action in hammers should be in the head or striking part; and, therefore, in striking with these instruments, the blow may be given with every advantage. But when an attempt is made to strike with an object in which the centre of action is at a place short of its extreme point, for instance, a common iron poker, a part of the action is expended towards the hand of the person who strikes, and he feels a disagreeable jarring sensation in his arm.

252. This definition of the centre of action applies only to the motion of bodies in a straight line. In the case of revolving bodies, the centre of action or percussion is a point in it, to which if an immovable obstacle be applied, the body will remain at rest without any tendency to move in any direction, and the axis will receive no shock. In straight rods, or bodies of any form, suspended as pendulums, the centre of oscillation is the same as the centre of action in revolving bodies.

MOTION IN ELASTIC BODIES.

253. In reference to the effects of collision, bodies are divided into three classes—hard, soft, and elastic. A hard body is one that suffers no change of form by the action of any force. A soft body is one that undergoes a change of form by this means. An elastic body suffers a momentary change of form by the action of any force impressed upon it, and immediately springs back, or recovers its original form. The first two classes are styled *inelastic* bodies.

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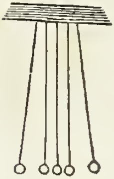
230. What of the centre of percussion?
231. What difference in the kind of motion?
232. Define inelastic bodies.

254. If two equal inelastic bodies be moving with equal velocities in opposite directions, and come in collision, each will destroy the onward motion of the other, and, consequently, both will be reduced to a state of rest.

255. If there be any elasticity in the bodies, they will, according to their degree of elasticity, rebound from each other, and a positive process of reaction will be exhibited. By this means there will be at once a counteraction and transmission of force. As above stated, when the bodies are perfectly elastic, the action and reaction are double those of inelastic bodies.

256. An example of the transmission of force or motion from one body to another, while the transmitting bodies remain at rest from their mutual counteraction of the force communicated, may be seen in the case of a row of billiard balls, which possess a certain elasticity. Place six billiard balls in a row on a smooth plane, and let them be all pretty close to each other, or even in contact. Then give a smart blow to the first ball, or, as we may call it, No. 1; it will instantly strike against No. 2, which will communicate the force to No. 3, and from 3 it will be given to 4, and from 4 to 5, and from 5 to 6. None of the balls, however, will sensibly move from the spot in which it rests, except the last of the row, which, having no ball to impinge upon, will roll away, and thus expend the force communicated by the blow upon No. 1. An experiment of this kind is generally performed upon a number of elastic balls of a small size, suspended in a row by threads, as in figure 9, in which case there is no friction to interrupt the process of action and reaction.

Fig. 9.



REFLECTED MOTION.

257. A body projected by a single force proceeds in a straight line till a new force act upon it, and send it on a

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233. Name the experiment with the billiard balls.
234. What of reflected motion, with examples?

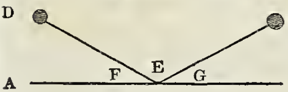
new line of direction. When a moving body is thus impelled into a new line by striking against some body, its motion is said to be *reflected.*

258. Examples of reflected motion are very common; as, for instance, when a rolling ball encounters an opposing stone in its path, in which case it flies off obliquely in a new direction; when we throw a thin piece of slate along the surface of a river, and make it skip from point to point; or when an apple, in falling from a tree, touches a lower branch in its descent, and rebounds in a slanting direction to the ground.

259. It is found by experiments, that moving bodies observe certain laws in respect to the line of direction they pursue in rebounding or being reflected from any impediment with which they happen to come in contact.

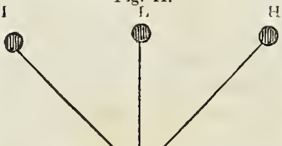
260. In the accompanying cut, figure 10, the line A B is a level marble slab. C is an ivory ball, which, being thrown towards the slab in the direction of C E, is reflected in the direction E D. Thus, the two angles F and G are exactly equal; and it is demonstrated, that a perfectly elastic ball striking a smooth wall or floor makes the same angle in leaving the point where it strikes that it does in approaching it.

Fig. 10.



261. Whatever be the angle at which the ball strikes the smooth fixed surface, the same rule will be observed to be followed. This is exemplified in figure 11. If the ball be dropped perpendicularly from L to K, it will rebound and return to L. If sent in the line H K, it will rebound or be reflected to I. The angle which a ball makes with the perpendicular line in going from H to K, is called

Fig. 11.



235. Explain the diagram.
236. Explain the diagrams, and angle of incidence.

the *angle of incidence*; and the angle which it makes in rebounding from the point at K to I, is called the *angle of reflection*. These angles are always equal.

262. A calculation of the angles of reflected motion is necessary in the case of presenting a shield or other object to ward off a missile or blow from the person. If the angle be too acute, that is, if the blow be too point-blank, the shielding object may be damaged, or perhaps destroyed; while, if the angle be obtuse, the object which gives the blow will slide off harmlessly. In playing at the game of billiards, the greatest exactness is required in the calculation of the forces and their directions according to the principles of reflected motion; and a similar kind of skill is required by those who handle the bat in the game of cricket.

THE LAWS OF MOTION CONTINUED.

COMPOSITION OF MOTION AND FORCES.

263. Hitherto we have spoken only of the motion of a body as produced by a single impulsive force, and turned aside or reflected by another force acting upon it; we have now to consider the subject of compound motion and force, or motion and force produced by two or more forces acting on a body in different directions at the same time.

264. If two or more forces act on a given point of a body, at certain angles, a single force may be found which would produce the same effect. This single force is technically called the *resultant* or *equivalent*. For instance, a wind blowing from the north-west, and a current setting from the north-east, both acting on a ship and tending to carry it with equal velocities in their own directions, the ship will be found to move in an intermediate direction, as if it were acted on by a single force, like a breeze, from due north.

It is usual, in treating of combinations of mechanical forces, to represent them by diagrams, the various lines of which are significant of the quantity or intensity of the

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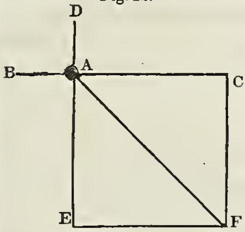
237. What use is the calculation of the angles of reflection?
238. What of compound forces, and the resultant?

forces, of the directions in which they act, and of the effects produced by them. This explains the reason for illustrating the action of forces by the following figures:

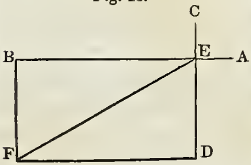
265. In figure 12, we have an example of motion produced by two forces in different directions acting on a body. A is a ball, which, having received a blow at B, is proceeding onward to C. At the point A, while on its course, it receives a blow equal to the former, which second blow would have been alone capable of carrying it to E in the same time that the first blow would have carried it to C. This new force, by changing the direction of the original motion, causes the ball to move in a line towards F, and the effect is the same as if the ball had been at first sent in the direction of A F by a single force. Practically it would be difficult to regulate blows with such nicety as to produce this line of motion, but in the theory of forces the law is as it has been stated. The line A F in the figure here drawn is termed the *diagonal of the square.*

Fig. 12.



266. Should the constituent forces be of different magnitudes, then the figure described may be a parallelogram, or oblong, as in the annexed cut, fig. 13. The force here, in the direction A B, is double that of the cross force C D, by which means the ball describes a diagonal line to F, and so forms a parallelogram, when we draw all the lines connected with the experiment. The parallelogram thus formed is called the *parallelogram of forces.* The two given forces acting in the directions E B, E D, are called *components*, and the single force in the direction E F is the *resultant.* The process

Fig. 13.



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239. Explain the first diagram, and the diagonal of the square.
240. Describe the second, and the italicised terms.

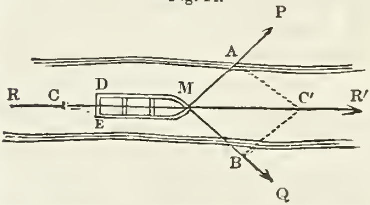
of finding a single force equivalent to two or more forces, is called the *composition of forces.*

267. The process of finding forces which will produce a motion equal to that of a single force, is called the *resolution of forces.*

The following are examples of the resolution of forces :—

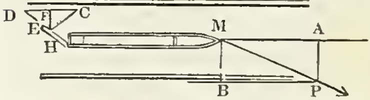
268. If a boat D E M floating on a river be pressed downwards in the line M C by a current, two forces P and Q, acting in the directions M P, M Q, may be found that will counteract the influence of the current, and keep the boat stationary. For, make M C to represent R, the force of the current, and make M C′ equal to M C, and find M A and M B as before, they will respectively represent P and Q. If two men, therefore, pull two ropes in the directions M P, M Q, with forces denoted by M A, M B, they would keep the boat at rest. If the ropes be tied to two posts at P and Q, the forces M A, M B, will represent their reactions.

Fig. 14.



269. Let H M be a canal boat, M P the rope by which it is drawn by a horse attached to it at P. The force of the draught being denoted by M P, it may be resolved into M A and M B, of which only M A is effective in drawing the boat forward; the other force M B tends to turn the head of the boat in the direction M B. This last force must therefore be counteracted, which is effected by means of the helm H E turned to an oblique position. When the boat is in motion, the water, being at rest, produces a re-

Fig. 15.

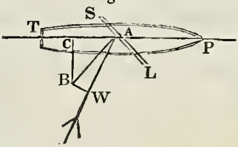


241. What is the first diagram?
242. Explain the record.

sistance or pressure against the helm. If C D denote the resistance, it may be resolved into H D and H C, of which H D produces no effect on the helm; therefore C H is the only effective pressure. Again, C H may be resolved into C F and F H, the latter of which tends to turn the stern of the boat in the direction F H, and thus counteracts the force M B, by tending to turn the boat round in an opposite direction; and the part C F tends to move the boat backwards, and thus, counteracting a part of the force M A, it retards the progress of the vessel. The two forces F H, M B, would move the boat sideways, or laterally, to the side of the canal; but this can be prevented by giving the helm a little more obliquity, for, from the length and shape of the vessel, it is much more easily moved in the direction of its length than of its breadth.

270. Let T P be a ship, S L its sail, W A the direction of the wind and its pressure on the sail. W A can be resolved into A B perpendicular to the sail, and B W parallel to it, the latter of which has no effect in pressing on the sail; therefore A B is the effective pressure on the sail. Were the vessel round, it would move in the direction B A. Let B A be resolved into C A and B C, the former C A acting in the direction of the keel or length of the vessel, or in the direction C A, and the latter perpendicular to it, or in the direction of the breadth. The former pressure C A is the only pressure that moves the vessel forward, the other B C makes it move sideways. From the form of the vessel, however, this latter force B C produces comparatively little lateral motion; any that it does occasion, is called *leeway*. By turning the helm, the vessel may be made to turn round in any direction by the pressure of the water upon it, if the vessel has also at the same time progressive motion.

Fig. 16.



271. The suspension of a kite in the air is another

243. Explain the diagram.

interesting illustration of the effect of the pressure of a current of air, the explanation of which belongs to PNEUMATICS.

THE LAWS OF MOTION CONCLUDED.

COMMON MOTION.

272. Motion, as has been stated (154), is called *common*, when participated in by two or more bodies. Thus, all things on the earth, including the atmosphere, have a motion in common with the earth; a person riding in a chaise has a motion in common with the chaise; a person in a moving vessel at sea has a motion in common with the vessel.

For convenience, we shall, in treating of this branch of our subject, use the terms larger and smaller body—the larger being understood to be the body on which the force to produce motion is immediately impressed, and the smaller being the body which is carried along by the body which has received this impression of force.

273. A large body is in motion; it is moving in a certain direction, at a certain velocity; every thing on it, or small body connected with it, partakes in its motion, and has a tendency to proceed in the same direction, and at the same velocity.

274. It appears strange that there should be a communication of motion from the larger body to the smaller, without the immediate intervention of impressed force on the smaller; but a little examination shows that such must necessarily be the case. The larger body has received the impulse to move, and this impulse is transmitted through the whole mass of the body, including all the small objects on its surface, and those which are any way connected with it in its propulsion. When a man is walking on the deck of a ship which is moving at the rate of ten miles an hour, he perhaps imagines that he has no more motion than if he were walking on the solid ground. But it would be incorrect for him to think so. His body,

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244. What of common motion, with examples?
245. How is it accounted for?

and every thing about his person, have received an impulse from the vessel; he possesses a velocity of ten miles an hour as much as the planks of the vessel do; and this onward motion he cannot divest himself of, as long as the ship continues to move at this rate of speed, or as long as he continues in connection with it.

275. On account of this participation of motion in all bodies moving in connected masses, it is observed that all objects whatever keep their proper places in or about the large moving bodies with which they are in contact, and hence no confusion takes place in the relative situation of objects on the earth by its motion. For example, when we leap from the ground, the earth does not slip away from below us; if we ascend in a straight line of direction, we fall down exactly upon the same spot whence we arose. When a man falls from the top of a mast of a moving vessel, he falls upon the deck upon a spot directly under the point whence he fell; the vessel does not leave him. When we are sitting in the cabin of a moving vessel, and let a small object drop from our hand to the floor, it falls on a point on the floor immediately below, the same as if it had been dropped in a house on solid ground; the floor does not leave it behind. When we are sitting in a rapidly moving coach, and, in a similar manner, let an object fall, it descends in the same manner to the bottom of the coach. The reason for these phenomena is that already mentioned—the small objects possess a motion derived from the larger; this common motion, or *motal inertia*, as some authors call it, is retained by the small objects during their descent, so that, while descending, they are also going forward; in other words, they display a composition of motion—a horizontal motion and a descending perpendicular motion.

276. One of the most beautiful examples of common motion, is that which is exhibited by an equestrian standing on a horse which is running round a circle, while he at the same time throws oranges from his hand and catches them in their descent. Notwithstanding his rapid motion,

246. Name the familiar examples of this motion.

the oranges which are thrown into the air do not fall behind; they return regularly to his hand. To counteract centrifugal force, he leans greatly inward; but this does not alter the law of motal inertia, which causes the oranges to return. He throws them almost sidewise in an inward slanting direction, and yet they come readily back to him. The reason for these phenomena is. that the oranges participate in the forces by which he himself is impelled and sustained.

277. Small bodies which have derived a motal inertia from a larger, continue to possess this motal inertia, after leaving the larger, until they meet with some new impression of force sufficient to alter their condition. If they were not pulled to the earth by attraction, and were not opposed by the atmosphere, they would go on moving in a straight line for ever.

278. When we drop a ball from the window of a moving coach, it continues to go forward, as if it were still in the coach, till it meet the ground, when it is stopped; thus, its motal inertia is destroyed. If we attempt to leap from a moving body, such as a coach or a boat, we continue to possess the motion which we previously had until we touch the earth, when we receive a shock by the destruction of our motal inertia. But if we leap from one moving body to another moving body which is going near it, on the same level, in the same direction, and at the same velocity, we sustain no shock. because the body upon which we leap possesses the same condition of motion as that which we possess.

279. When a man standing on the ground shoots at a bird on the wing, he requires to follow its motion by keeping his gun moving when presented at it; but if he be standing on the deck of a ship sailing at the rate of ten miles an hour, and point his gun at a bird flying in the same direction and at the same velocity as the ship, then he is placed in the same condition as the bird; he does not require to move his gun, as if following the bird. In

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247. Repeat and explain the illustrations cited.
248. Describe the uses of understanding this law.

taking aim at a bird on the wing from the solid ground, it requires considerable skill to prevent the shot from proceeding to a point behind the bird, because the shot is entirely destitute of motal inertia on being fired, unless it be previously put in motion. But a bullet on leaving a gun which is moving at the same rate as the bird, and in the same direction, keeps going on in the direction of the bird, because it retains the motion it had in common with the gun. The bullet in this case does not go in the direction of the gun, but obliquely, so as to keep up with the motion of the bird, so that the same effect is produced as if the shot had been fired from a fixed gun on land to a fixed point in the air in advance of the bird. Should the bullet be fired from a gun in a moving vessel, for instance a ship sailing westward to a fixed point on land, then a certain allowance must be made for the motal inertia of the bullet; it must be fired a little eastward, and the motal inertia will carry it westward to the object.

280. Objects falling from bodies moving in an onward direction to those which are at rest, are regulated by the same law that governs projectiles. The falling objects, as formerly mentioned, are affected by two motions—one in a horizontal and the other in a descending direction. When these motions are unequal, the falling body describes a curve in its descent, the convex side of the curve being uppermost. Thus, motal inertia and the motion produced by projectile impulse are the same thing; and hence, powerful centrifugal force in the sun, sufficient to disengage a portion of its mass, would be equivalent to a projectile impulse from it as a fixed body.

281. In consequence of the general participation of common motion in all things connected with a moving body, there can be no consciousness of motion in the living beings carried about by it, provided the motion be perfectly smooth, and there be no means of observing bodies which are at rest. Thus, on account of our possessing a motion in common with the earth, which moves with perfect smoothness, we can neither see nor feel the earth moving.

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249. When are we conscious of participating in this motion?

We, however, see the sun, which seems to us to be in motion in reference to the earth, but which, by various means, we know to be at rest; and hence we are assured of the earth's diurnal rotation on its axis, and its annual or planetary motion round the sun. In the same manner, a person sitting in the cabin of a smooth-sailing ship, and not looking out at the windows, cannot, by his mere sensations, tell that the vessel is moving; but if he look at the shore, which is at rest, he is immediately sensible of the progressive motion of the vessel.

252. In looking from a moving body, as from the earth to the sun, from a ship to the shore, or from a coach to objects on the wayside, a delusive feeling prevails that it is not the body you are upon, but the body which is at rest, that is really moving—going in a direction contrary to that of the body you are connected with. This is in consequence of our possession of motion in common with the moving body. We are under an influence, or in a condition, that renders us incapable of seeing our own motion: and, hence, the error which the sense of vision leads us to commit, is left to be rectified by an exertion of the understanding.

The subject of the next Book is MECHANICS, or a treatise on MECHANICAL POWERS and MACHINERY, being the application of the laws above demonstrated to contrivances for lessening and aiding human labour.

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250. Why are we not so, and when?
251. To what mistakes are we liable, and why?

THE END.

STEREOTYPED BY L. JOHNSON AND CO.
PHILADELPHIA.

ELEMENTS

OF

NATURAL PHILOSOPHY.

PART II.

MECHANICS.

CHAMBERS' EDUCATIONAL COURSE.

INTRODUCTORY OBSERVATIONS

BY

THE AMERICAN EDITOR.

This second book of Natural Philosophy is designed to follow the work on Matter and Motion, which is introductory to practical Mechanics, and should first be made familiar to both the teacher and scholar. The catechetical questions upon every page of both these volumes are designed to furnish such an analysis of every topic as shall render the acquisition of the elements of these departments of science so easy that none may be deterred from their cultivation; and if the suggestions of the preface be acted upon, and the learners be encouraged to construct, with their own hands, simple and rude apparatus, which shall illustrate the principles taught, no study will be more delightful to children than the departments of nature and art to which these sciences introduce them.

Nothing can be more gratifying to the philanthropist, than to witness the march of mind, characteristic of the present age, as exemplified in the diffusion of scientific knowledge among the masses of the people, by the adaptation of the teachings of philosophy to the young and rising generation. Instead of locking up knowledge in these higher walks of science in cloisters and academic groves, accessible only to a favoured few, the teachings of philosophy are now disrobed of all their mystery, and by cheap publications they are rapidly becoming the property of all.

The educational series, of which this little volume forms a part, is calculated to initiate the young into the elements of all the sciences, even in the common school. The poorest children of the present generation may thus become wiser than their parents, and understand more of philosophy and science than was the lot of any in the previous century, except those whom fortune favoured with wealth and thorough collegiate training, extending to adult years, and even consuming the greater part of life in the seclusion of study. And a taste for such pursuits being thus early acquired, and the habit of investigation into the nature and causes of things becoming, as it will, a part of their mental constitution, it is impossible to predict, or to limit, the practical improvements and useful discoveries which will result, or the amount of increase to human progress and happiness which this generation shall witness.

The admirable "Lectures of Dr. Lardner on Science and the Useful Arts," now in the course of publication, are so well adapted to the popular mind, that as a sequel to these volumes, they cannot fail to be appreciated, and they will be eminently useful in proportion as they are read by those who are trained in their schools to estimate the importance and necessity of philosophy in every department of art, and in the economy of human life.

Let parents and teachers then avail themselves of this series and other kindred publications to cheapen knowledge, and diffuse it abroad far and wide among the masses, in conformity with the spirit of the age.

D. M. R.

PREFACE.

THE present Treatise, comprehending MECHANICS, the ELEMENTS of PRACTICAL MACHINERY, and MOVING FORCES, forms the second department of Natural Philosophy, according to the arrangement described in the Preface to the LAWS of MATTER AND MOTION.

A passage of that preface, as of general application, may appropriately be repeated here:—"In exercising a class in this and other departments of Natural Science, it will be found to be of considerable importance to cause each paragraph to be mastered or thoroughly understood before proceeding to what follows; for the whole constitutes a structure in which each part rests on what has gone before it. The pupil should, also, not only *read*, but be induced to *think* on the nature of the principles which are unfolded, and led to find examples of their action in the every-day concerns of life, and the common phenomena of the universe." It is further suggested, that pupils should, by the aid of small pieces of wood, cord, and other easily procured materials, endeavour to work out, with their own hands, the various principles of Mechanics which are demonstrated in the following pages. It is believed, that by no other means could these valuable principles be so well fixed in the memory, or have such a powerful effect in cultivating the understanding.

In the present, as in the preceding Treatise, very great pains have been taken to render the language simple and intelligible, so that the learner may find at least no technical difficulty in his path. Those who are desirous of pursuing the study of Dynamical and Mechanical science, beyond the limits of these elementary works, and who possess a knowledge of Algebraic and Mathematical formulæ, are recommended to have recourse to the excellent "Treatise of Mechanics, Theoretical and Practical, by Olinthus Gregory;" the "Introduction to Natural Philosophy, by William Nicholson;" or to the Treatises of Wood, Leslie, and Whewell No popular and comprehensive treatise on the properties of matter and doctrines of forces, excels the well-known Elements of Physics, by Dr. Neil Arnot. There are also a few compendious productions of American writers which may be consulted, particularly those of Gale, Comstock, and Bigelow, to which the Editors have to acknowledge themselves indebted for some useful hints. Engineers, mill-wrights, and other artisans, who require to make practical calculations, will find a small work, entitled "Burton's Compendium of Mechanics," worthy of their attention.

CONTENTS.

NATURAL PHILOSOPHY.

MECHANICS.

GENERAL DEFINITIONS.

1. The application of the laws of motion and forces to objects in nature or contrivances in the arts, forms the branch of Natural Philosophy usually treated under the head Mechanics, Mechanical Powers, or Elements of Machinery.

2. The original signification of the word *machine*, which is the root of the various terms *mechanic, mechanical*, and so forth, was art, contrivance, or ingenuity.

3. When the term *mechanic*, or *mechanical*, is applied to the action of forces—as mechanical powers—it is meant that certain powers are exerted, or motion produced, by the action of particles or masses of matter, solid or fluid, one upon another. Thus, *mechanical action* is applied to the action of forces that produce no change in the constitution of bodies, and is therefore distinguished from *chemical* or any other species of action.*

4. In Natural Philosophy, machines are spoken of as being of two kinds—simple and complex. A simple ma-

* In scientific works, the term *mechanics* is usually restricted to the action of *solids*, while *mechanical* or *mechanically* is applied to the action of both solids and fluids. For example, the wearing away of stone by the action of water, is said to be *mechanical action*, or that the water acts *mechanically*.

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1. Define the science of Mechanics, and the word itself.
2. How is mechanical distinguished from chemical force?
3. How are machines divided primarily?

chine is equivalent to a tool or instrument, and a complex machine is an engine, in which different parts combine to produce the required effect. In common phraseology, these distinctions are not very minutely attended to.

5. Machines are, under all denominations or circumstances, only instruments through which power may be made to act. They only convey, regulate, or distribute, the force or power which is communicated to them from some source of motion, and never create or generate power. But although a machine does not create power, or give more power than it has received, it practically applies the power which has been communicated to it, in so convenient and easy a manner, that a result ensues almost as surprising as if it had actually generated the whole or a portion of the power it exhibits.

6. The main purpose required in mechanical operations is to overcome, oppose, or sustain, a certain resistance or force. This purpose is obtained by applying another species of force. According to the usual phraseology, the resistance or force to be overcome is called the *weight*, and the force which is applied is called the *power*.

7. The ability of applying force by the human hands, without the aid of instruments or machines, is very limited. In almost all our operations of art, it is found necessary to call in the aid of instruments or machines of some kind. All the instruments which mankind have adopted for their use—from a piece of stick with which the savage scratches the ground as a plough, to the most elegant piece of mechanism—act upon certain fixed principles in nature, which a long course of experience and scientific investigation has developed.

8. The mechanical powers, which exhibit the working of these principles, are strictly only three in number, namely—

1. The Lever.
2. The Pulley, or Cord.
3. The Inclined Plane.

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4. What part do they enact?
5. What is the main purpose of mechanical operations?
6. Define the weight and power in this relation.
7. The importance and variety of machinery.

These may be called the PRIMARY MECHANICAL POWERS; and from two of them, the Lever and Inclined Plane, other three are formed, as follow—

1. WHEEL and AXLE, from the LEVER.
2. WEDGE, from the INCLINED PLANE.
3. SCREW, from the INCLINED PLANE.

These may be called the SECONDARY MECHANICAL POWERS. The six altogether form the elements of every species of machinery, however complex.

OF LEVERS.

9. The lever is one of the most important and extensively used of all the mechanical powers, and its operation exhibits some of the leading principles in mechanics.

10. A lever is a rod, or bar of iron, wood, or any other material which is moveable upon or about a prop or fulcrum, or about a fixed axis. It is called a *lever*, from a French word signifying to raise, and has been applied to instruments for raising or lifting weights.

11. Three elements contribute to the operation of the lever—the *power*, the *fulcrum*, and the *weight*. The power is the force applied, the fulcrum is the prop or support, and the weight is the resistance or burden to be lifted. The terms *power* and *weight* have merely a reference to the manner in which the machine is used; strictly, both the power and the weight are *forces* the same in character and action.

12. There are three kinds of levers, differing according to the relative situation of the power, fulcrum, and weight. Each of these kinds consists of a straight bar, and in theoretical calculations is supposed to be in itself destitute of any gravity or degree of heaviness. In theory, also, the forces which are applied are supposed to act at *right angles* to the fulcrum.

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8. Name the primary mechanical powers, and the secondary.
9. Whence are the latter derived?
10. Define a lever.
11. What elements are concerned in its action?
12. Define each of these and which are forces.
13. Varieties of levers, and theory of their action.

13. In the first or most simple kind of lever, " the fulcrum is disposed between the power and the weight." In the second kind, " the weight is disposed between the power and the fulcrum." In the third kind, " the power is disposed between the weight and the fulcrum."

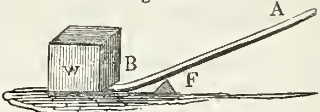
FIRST KIND OF LEVER.

14. In the first kind of lever, " the fulcrum is disposed between the power and the weight." Figure 1, is an example. A to B is a straight bar, resting on a prop or fulcrum F. From A to F is the long arm of the lever, and from F to B is the short arm. P is the power, or a certain force drawing down the extremity of the long arm at A. W is the weight suspended from the extremity of the short arm at B.* The object is, to cause P, which is supposed to be a small weight, to balance or overcome W, which is supposed to be a weight much heavier. Practically, the force of a man pressing upon the extremity of the handle of the lever at A, will effect with ease, in lifting the heavy weight W, what it would require a much greater force to accomplish by pressing upon the long arm at a point half way betwixt A and the fulcrum.†

Figure 1.

15. This is more clearly exemplified in figure 2, which represents a lever placed conveniently for raising a square block W, which is the weight. On pressing down the extremity of the long arm of the lever at

Figure 2.



* Some authors call the long arm *the arm of the power*, and the short arm *the arm of the weight*.

† *Note* 1.—Properly speaking, the power does not sustain the weight, for both are supported by the fulcrum ; the power, in the case of equilibrium, only prevents the weight from producing a motion of rotation.

Note 2.—In every machine, simple or complex, besides the power required to balance the resistance, there must be some additional power applied in order to produce motion, or overcome the inertia of rest of the body.

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14. Define each of the three in the arrangement of the forces.
15. Explain the diagram, and the notes.

A, the point of the short arm B raises the block. F is an object lying on the ground to press against as the fulcrum. As in the case of figure 1, "the force of a man pressing upon the extremity of the handle at A, will effect with ease, in lifting the weight W, what it would require a much greater force to accomplish by pressing upon the long arm at a point half way betwixt A and the fulcrum."

16. The principle in mechanics which produces this phenomenon is very simple, and is explained by what is called the LAW OF VIRTUAL VELOCITIES, or, from its general application, the GOLDEN RULE OF MECHANICS.

17. This law or rule is, THAT A SMALL WEIGHT, DESCENDING A LONG WAY, IN ANY GIVEN LENGTH OF TIME, IS EQUAL IN EFFECT TO A GREAT WEIGHT DESCENDING A PROPORTIONABLY SHORTER WAY IN THE SAME SPACE OF TIME. In other words, what is gained in velocity or time, is lost in expenditure of power.

18. Another way of stating this important law is as follows:—IN THE CASE OF EQUILIBRIUM, IF A MOTION BE GIVEN TO THE MECHANICAL POWER, THEN THE POWER MULTIPLIED BY THE SPACE THROUGH WHICH IT MOVES, IN A VERTICAL DIRECTION, WILL BE EQUAL TO THE WEIGHT MULTIPLIED BY THE SPACE THROUGH WHICH IT MOVES IN A VERTICAL DIRECTION.

19. This principle, which applies to every mechanical movement in the case of equilibrium, has been illustrated by a reference to the property of attraction of gravitation. What is called weight, is only an effect of gravity on the atoms of matter. In figurative language, every atom is drawn towards the earth by an invisible line or cord of attraction; and when one atom rises or falls ten inches, the same quantity of attraction is drawn out from, or sent back to the earth, as if ten atoms were to rise or fall only one inch.

20. Thus, by a proper mode of applying the power, we

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16. What of this diagram?
17. By what names has this principle of action been called?
18. What is this law, and how stated?
19. What of atomic gravitation?
20. What illustration is stated?

may cause a weight of one pound, by moving through a space of ten feet, to raise another weight of ten pounds, moving through a space of one foot; or (the reverse) by a weight of ten pounds moving through the space of one foot, we may make a single pound move through the space of ten feet. But by none of the mechanical powers shall we be able, by moving a weight of ten pounds through one foot, to move a single pound through eleven feet; nor, by a single pound moving through a space of nine feet, shall we be able to raise a weight of ten pounds through one foot.

21. Neither by the power of the lever, therefore, nor by any other of the mechanical powers, can we make any absolute increase of the power which is applied. In other words, the quantity of power expended in any great and instantaneous effort, is exactly the amount of the power which has been previously accumulated. All that we can do to procure mechanical advantage, is to accommodate the velocity, force, or direction of the applied power, to the purposes which we may have in view.

22. To apply this principle to the lever, figure 1 or 2, a small force at A is equal to double the force exerted at a point half way betwixt A and the fulcrum, yet, in both cases, the same amount of mechanical power is expended. A slight push downwards at A, by being continued for one minute, is equal to a push of double the force at a point half way towards the fulcrum, continued for the same time. Any amount of force, therefore, can be exerted with ease at the extremity of the long arm of the lever, provided we choose to make the arm long enough and strong enough.

23. It may possibly be said that it would be as expeditious to push down the extremity of the long arm of the lever, as to push down the arm at a point nearer the fulcrum. Practically, in small levers this may be the case; but when levers of considerable length have to be used, and a succession of depressions and raisings are necessary, it will be found that more time is spent in working with a

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21. What of the increase of power, not absolute?
22. How is this explained?
23. What of long and short levers?

long than a short lever. For when the sweep of the lever is inconveniently long, the person using it has to move his body quickly up and down over a larger space, and is sooner fatigued. For this reason, although a boy with a long lever may balance as great a weight as a man with a shorter one, yet, in raising weights successively by it, the boy would be sooner fatigued.

24. It is a general rule that "the force of the lever increases in proportion as the distance of the power from the fulcrum increases, and diminishes in proportion as the distance of the weight from the fulcrum diminishes." In making calculations to ascertain the proportions to be observed betwixt the power and the weight, regard must be paid to the respective lengths of the long and short arms of the lever. We must also fix what are to be the units of weight and distance, and let them be the same on both ends. If we state inches to be the unit of length of the short arm, inches must be the unit of length of the long arm; and in the same manner, if ounces be made the unit of weight of the short arm, ounces must be made the unit of power of the long arm.

25. Rule.—Multiply the weight by its distance from the fulcrum; then multiply the power by its distance from the same point, and if the products are equal, the weight and the power will balance each other.

26. Example first.—Suppose a weight of 100 pounds on the short arm of a lever, at the distance of 8 inches from the fulcrum, then another weight or power of 8 pounds would be equal to this, at the distance of 100 inches from the fulcrum. Because 8 multiplied by 100 produces 800, and 100 multiplied by 8 produces 800—and thus the weight and the power would mutually counteract each other.

27. Example second.—Suppose we wish to calculate what power should be employed at the end of the long arm of a lever to balance a given weight at the end of the short arm. We multiply the weight by the length of its

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24. What general rule is stated?
25. How are the proportions to be calculated?
26. Give the rule, with examples.

arm. This gives us a product; then divide that product by the number of inches in the long arm, and the result or quotient is the power. Thus, a weight of 10 pounds multiplied by 10 inches, as the length of the short arm, gives a product of 100. If the length of the long arm be 20, we find how many twenties are in 100, and there being 5, consequently 5 pounds is the power. In this instance, the mechanical advantage is two to one—that is, the power is twice as small as the weight.

28. The common spade used in delving in gardens offers a familiar example of simple lever power, when employed in raising the earth from its place to turn it over. Figure 3 represents an equally familiar example, namely, a wood-

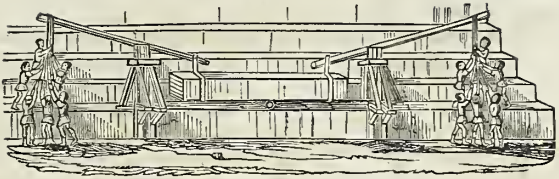
Figure 3.

sawyer or carpenter moving a log of timber from its place, by means of a long pole or beam of wood. Stone masons use a lever of iron of this description, called a crow-bar.

29. The ancient Egyptians were acquainted with the power of the lever, and employed it to raise the large blocks of stone of which the Pyramids are composed. The lever used by them, however, was of a rude description, and required many men to wield it. According to Herodotus, a Greek historian, who writes of Egypt, it consisted of a beam of wood, fixed by a joint or axle on an upright frame, which was the fulcrum. The longer arm of this lever was several times the length of the shorter arm. To lift each block, it was necessary to employ two of these

27. What familiar illustrations are cited ?
28. What ancient levers are described ?

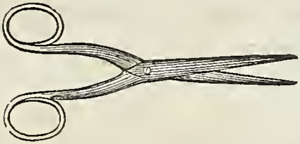
Figure 4.



levers, with ropes attached, one lever at each end of the block. A number of men were employed to pull the ropes, as represented in figure 4. After the block was raised one step up on the exterior of the pyramid, the levers were lifted up another step higher, and the block raised to their level. In this clumsy and tedious manner were the Pyramids of Egypt erected.* In modern times, the principle of the lever is employed in a much more speedy and efficacious manner in raising or lowering blocks of stone for masonry, or in loading and unloading bales of goods in commerce, by means of a machine called a crane, hereafter to be described.

30. The power of the first kind of lever is frequently seen to operate in machines or instruments having two arms. The most common examples of this nature are pincers, scissors, and similar instruments. In a pair of scissors here represented, the two limbs are seen

Figure 5.



* To erect one pyramid alone, called the Great Pyramid, required the work of 100,000 men for twenty years ; and although these men were compelled to work without wages, like slaves, the expense incurred was enormous. In the present day, the steam-engines of England, by a united effort, cou[illegible] lift the whole of the stones of the Great Pyramid into their places in about twenty hours.

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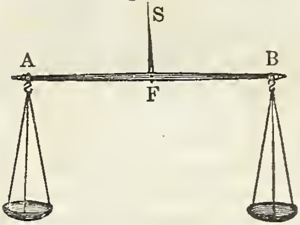
29. How would such machines be regarded now ?
30. By what means would the moderns do such work ?
31. Explain the second diagram.
32. What do we learn in the note ?

to be joined with a rivet at the centre, which is the fulcrum of both.

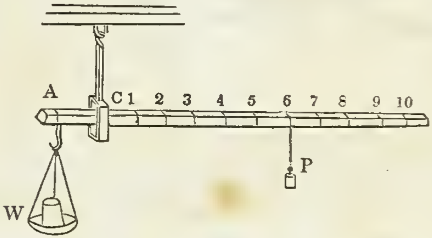
31. A common scale beam for weighing, used by shopkeepers, is an example of the first kind of lever formed with two arms of equal length, and suspended over the centre of gravity, so that the two extremities balance each other. See figure 6. S is a string or line suspending the beam A B at a central point F, which is the fulcrum. The point of suspension or pivot is sharpened to a thin edge, so as to allow the arms to rise or fall with as little friction as possible, when any thing is put in the scales.

Figure 6.



32. There is another kind of balance, called a *steelyard*, which consists of a lever with arms of unequal length, and acts upon the principle of distance from the fulcrum on the long arm compensating for weight on the short arm as defined in paragraphs 26 and 27. Figure 7 is a representation of the steelyard balance. C is the fulcrum or pivot by which the beam is suspended, and freely plays as on an axis. A is the short arm, and the opposite end is

Figure 7.



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33. Explain the first diagram, and its action.
34. What of the second?

the long arm. W is the scale for the reception of the article to be weighed. The long arm is graduated into divisions by marks, each mark denoting by a figure a certain number of pounds or ounces. P is a weight of a certain heaviness, and being moveable by a ring, it can be slipped along the bar to any required point. The same weight is always used, and thus constitutes one of the principal conveniences of this kind of balance. In proportion as the article to be weighed in the scale W is heavy, so is the weight P slipped along to a greater distance from the fulcrum; and when it is brought to a point where it balances the article, the figure on the bar at that point indicates the amount of the weight. If P be one pound, and if, when suspended from the division at 6, it balance the weight at W, it is evident that the weight will be six times P, or six pounds And so on with all the other divisions.

33. The steelyard, though not so ancient as the common balance, is of considerable antiquity. It was used by the Romans, and has long been in use among the Chinese. Neither the common balance nor the steelyard is suitable for showing the varying weight or heaviness of an article at different latitudes of the earth's surface, because the weights employed are equally affected with the attraction of gravitation and centrifugal force, as the article to be weighed. For this reason the difference of weight resulting from the causes mentioned, can only be demonstrated by a balance formed of a spring of elastic metal. By suspending the article from the spring, it pulls it out to a certain extent, and so indicates the weight on a graduated scale on the instrument. As the spring acts the same in all latitudes, it serves as a fixed or unalterable power, while the article to be weighed is liable to an alteration in its weight or heaviness according as it is brought near or carried from the equator.*

* See explanation of variability of weight in paragraph 68, LAW, MATTER, and MOTION.

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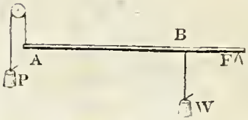
35. What objection lies against both?
36. What of the spring balance?

SECOND KIND OF LEVER.

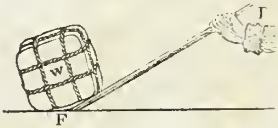
34. In the lever of the second kind, the weight is placed between the power and the fulcrum, as in figure 8. The line from A to B is the long arm; B to F is the short arm. W is the weight, and P is the power. The object required by this lever is to lift the weight W by raising the extremity of the lever at A. In this as in the case of the first kind of lever, the power is increased in proportion to its distance from the fulcrum.

Figure 8.



35. Examples of this kind of lever power are common. One of the most familiar is that of a man pushing or lifting forward a bale of goods, as represented in figure 9, in which the bale or weight W presses against the lever between the power P and the fulcrum F.

Figure 9.



36. Another example of the second kind of lever is that of a man using a wheelbarrow, as represented in figure 10. A point in the wheel of the barrow where it presses on the ground, is the fulcrum. The body of the barrow, with its load, is the weight. And the two handles lifted or held up by the man form the power. In proportion as the man shortens or lengthens the handles in holding them, so does he increase or diminish the weight he has to sustain.

Figure 10.

37. Two men carrying a load between them on a pole is also an example of the second kind of lever. The load may either rest upon or be dependent from the pole. In

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37. Define the second kind of lever.
38. What of each of the diagrams?
39. What of the two diagrams?

the case of two porters carrying a sedan chair, by means of two poles, the load or weight is partly above and partly below the line of the lever. In the case of porters carrying a barrel slung from a pole, as in figure 11, the weight is altogether below the lever. In both instances the principle is the same. Each man acts as the power in moving the weight, and at the same time each man becomes a fulcrum in respect to the other. If the weight hang fairly from the centre of the pole, each man will bear just a half of the burden; but if the weight be slipped along to be nearer one end of the lever than the other, then the man who bears the shorter end of the pole, supports a greater load than the man who is at the long end. The weight increases precisely in proportion as it advances towards him. Sometimes, when a man and a boy are carrying a hand-barrow between them, the man, in order to ease the weight as much as possible to the boy, holds by the arms of the barrow near to where they join the loaded part.

Figure 11.

38. In yoking horses to the extremities of cross bars in ploughs, coaches, or other vehicles, care requires to be taken to hook the cross bar to the load at its centre, otherwise one horse will have to pull more than the other.

39. An inflexible beam resting on supports or fulcra at its two extremities, acts similarly as a lever of the second kind. Should no weight be appended to its centre, the weight of the material itself, when the extension is considerable, will be enough to bend it down, and even to break it. Extended flexible cords or chains, are from this cause always bent down in the middle, no power of extension being able to overcome the gravity of the materials, which will give way before they can be rendered perfectly straight. The bended string of a boy's paper kite is an example of this powerful influence of gravity of materials.

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40. What of the weight of the material itself?
41. What of the string of a kite?

40. The instrument used for cracking nuts (figure 12) is an example of the second kind of lever with two arms or limbs. The fulcrum is the joint which connects the two limbs; the nut between them is the weight or resistance; and the hand which presses the limbs together, in order to break the nut, is the power. As each limb is a lever, a double lever action takes place in the operation.

Figure 12.

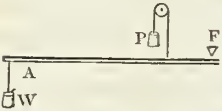
41. The oar of a boat in rowing is a lever of the second kind. The hands of the sailor who pulls constitute the power; the boat is the weight to be moved; and the water against which the blade of the oar pushes, is the fulcrum.

42. The second kind of lever is sometimes employed as an instrument of pressure. The point of the short arm is, for example, pushed into a crevice or hole in a wall, the fulcrum is the object to be pressed, and at the extremity of the long arm a heavy weight is applied. In this rude but efficacious manner are cheeses pressed in some parts of the country.

THIRD KIND OF LEVER.

43. In the lever of the third kind, the power is placed between the weight and the fulcrum. Figure 13. The fulcrum is at the extremity of the short arm at F; the weight W is dependent from the extremity of the long arm at A; and P is the power.

Figure 13.



44. In this kind of lever, the power acts with considerable disadvantage, or with small effect; but this disadvantage is compensated by an opposite advantage, which is frequently of great importance in the operations of both nature and art. The advantage consists in the velocity with which a small power will cause the extreme point of the long arm

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42. Explain the first diagram.
43. What of rowing a boat, and of pressing cheeses?
44. Explain the second diagram.

of the lever to move over a great space. This lever, therefore, whether in nature or art, is used only when a great space has to be traversed quickly by the long arm; but in this case, the power must always be greater than the weight.

45. An example of this kind of lever is found in the foot-board of the turning-lathe. Figure 14. The foot of the workman presses lightly on the board or plank near the end which rests on the ground, or fulcrum, and causes the opposite extremity of the board to move in a downward direction over a considerable space. A spring over-head, or a crank, pulls the board up again by means of a string S; the workman again presses it downward, and so a constant action of the string or cord which works the lathe, is easily produced.

Figure 14.

46. A man wielding a flail with two hands, and similar instances of using weapons, are also examples of the third kind of lever action. A similar action is observable when we use fire-tongs; a small motion of the fingers near the joint of the instrument, causes the legs, which are two levers, to open or shut over a considerable space.

47. Before the peculiar advantages of this kind of lever became known, or were appreciated, it was called the *losing lever.*

48. The movements in the limbs of animals are generally produced by the action of this kind of lever power.

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45. What is gained by this kind of lever?
46. Explain the first diagram.
47. What erroneous name was formerly given, and why?
48. What example is found in animal structure?

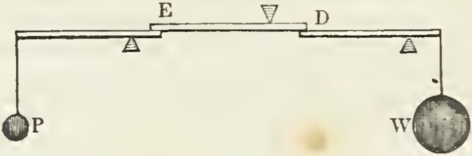
OF COMPOUND AND BENT LEVERS.

COMPOUND LEVERS.

49. When several levers of the simple kinds are connected together, and are made to operate one upon the other, the machine so formed is called a Compound Lever. In this machine, as each lever acts with a power equal to the pressure on it of the next lever between it and the power, the force is increased or diminished according to the number or kind of levers employed.

50. Figure 15 represents a compound lever, consisting

Figure 15.



of three simple levers of the first kind, placed in a line, and each working on its own fulcrum. The desired object of the machine is for a small force or power at P, to move or balance a large weight at W. The same rule applies, in calculating the action of this combined lever, which has already been given for the simple lever, namely, " multiply the weight on any lever by its distance from the fulcrum; then multiply the power by its distance from the same point, and if the products are equal, the weight and the power will balance each other." Or, for the form of lever in the figure, " multiply the length of the long arm by the moving power, and multiply that of the short one by the weight, or resistance."

51. It is supposed that the three levers in the figure are of the same length, the long arms being six inches each,

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49. Define a compound lever.
50. Explain the second diagram.
51. By what rule is the force of this combined lever calculated ?

and the short ones two inches each; required—the weight which a moving power of 1 pound at P will balance at W. In the first place, 1 pound at P would balance 3 pounds at E; we say 3, because the long arm being 6 inches, and the power 1 pound, 6 multiplied by 1 is 6; and the short one being 2 inches, we find that there are 3 twos in 6, therefore 3 is the weight. The long arm of the second lever being also 6 inches, and moved with a power of 3 pounds, multiply the 3 by 6, which gives 18; and multiply the short arm, being 2 inches, by a number which will give 18; we find that 9 will do so (9 twos are 18); therefore 9 is the weight borne at the extremity of the short arm of the second lever at D. The long arm of the third lever being also 6 inches, and moved with a power of 9 pounds, multiply the 9 by 6, and we have 54; and multiply the short arm, being 2 inches, by a number which will give 54; we find that 27 will do so (twice 27 is 54); therefore 27 is the weight borne at the extremity of the short arm of the third lever. Thus 1 pound at P will balance 27 pounds at W. Or 1 ounce at P will balance 27 ounces at W—the proportions being always alike, whatever denomination of weight we employ.

52. In this instance, the increase of power is comparatively small, because the proportion between the long and the short arms is only as 2 to 6, or 1 to 3. If we make the proportions more dissimilar, as 1 to 10, or 1 to 20, the increase of force becomes very great. For example, let the long arms be 18 inches each, and the short ones 1 inch each, and 1 pound at P will balance 18 pounds at A, and the second lever will be pushed up with a power of 18 pounds. This 18 being multiplied by the length of the lever 18, gives 324 pounds as the power which would press down the third lever. Lastly, multiply this 324 by the length of the lever 18, and the product is 5832 pounds, which would be the final weight at W which 1 pound at P would raise.

53. The following is a general rule for calculating the

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52. Repeat the calculations of these three levers.
53. How may the force be increased?

advantages of a compound lever consisting of any number of levers, whether equal or not:—Call the arms of the different levers next the power the *arms of power*, and the other arms the *arms of weight;* then, if the lengths of the arms of power and the power itself be successively multiplied together, the product will be equal to the continued product of the arms of weight and the weight, when the power and weight are in equilibrium.

54. A similar result to that of a combination of levers, might be produced by only one lever, provided it were long enough, but the operation would be both clumsy and inconvenient. By combining levers, and making them act one upon another, great weights may be balanced within a small compass, and with an exceedingly small power. On this account, machines are constructed with combinations of levers, for weighing loaded carts and other heavy burdens. The cart is wheeled upon a sort of table placed level with the ground, beneath which the levers are arranged; and a small weight placed on a scale attached to the extreme point of the first lever, balances the load, which rests on the table above the last lever. This species of weighing machine is often to be seen at toll-bars.

BENT LEVERS.

55. In the foregoing examples of lever powers, the levers or bars are supposed to be straight, and the powers and weights, or forces, are supposed to act at right angles with them.

56. Levers are frequently *bent* in their form, for purposes of convenience, and the powers and weights often act *obliquely*, or not at right angles.

57. In calculating the mechanical advantage of bent levers, the chief matter for consideration is *obliquity* in the direction of the applied power and weight. Obliquity in the action of the forces, generally diminishes the mechanical advantage.

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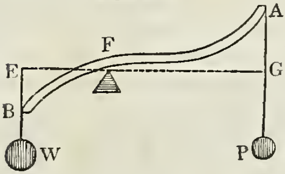
54. What of the arms of power and of weight?
55. To what uses are compound levers applied?
56. What of bent levers and their action?

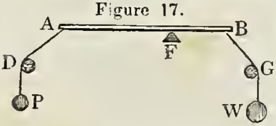
58. Whatever be the form of the lever, or the direction of the power and the weight, the mechanical advantage of the power or the weight is always represented by *a line drawn from the fulcrum, at right angles to the direction in which the forces are respectively exerted.*

Figure 16.



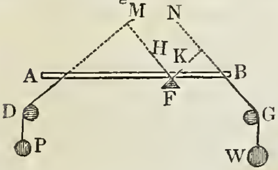
59. Figure 16 is a bent lever, with the power P hanging from A, and the weight W hanging from B. In this case, both the power and the weight act at right angles to an ideal line, drawn as from E to G across the fulcrum, which strikes the lines of direction of the forces at right angles. This ideal line, therefore, represents the true lever of calculation, and we proceed with it according to the ordinary rule for calculating lever powers (25). In this manner, the bending goes for nothing.

Figure 17.



60. Figure 17 is a straight lever with the power P acting obliquely from D to A, and the weight W acting obliquely from G to B. In order to calculate the power of this kind of lever, we must draw lines as represented in figure 18. First, we draw a line obliquely upwards in the direction of the pulling power. This line is seen dotted from A to M. We then draw a line off from it, or *at right angles* with it, to F the fulcrum. This line is seen dotted and marked H. We next draw a line obliquely upwards in the direction of the pull of the weight, as from B to N; and in the same manner as before, draw a line *at right angles* from it. This line

Figure 18.



57. Explain the diagram.
58. Explain the first diagram.
59. What does the second show?
60. How does the third differ?

is seen dotted and marked K. We have now found an ideal lever, with two arms, H and K. This ideal lever, is the true lever of calculation, and we proceed with it according to the ordinary rule for calculating lever powers (25).

61. The next example, figure 19, represents the power and weight acting obliquely the same as in figure 18; but in this case the lever is bent. The bending of the lever, however, does not affect the rule of calculation, which is the same as in figure 18. We begin by drawing a line obliquely upwards in the direction of the pulling power. This line is seen dotted from A to C. We then draw a line off from it, or at *right angles* with it, to F the fulcrum. This line is seen dotted from C to F. We next draw a line obliquely upwards, in the direction of the pull of the weight; and in the same manner as before, draw a line at *right angles* from it (as from D) to F. We have now found an ideal lever; from C to F being the long arm, and F to D the short arm. This ideal lever is the lever of calculation, and we proceed with it according to the ordinary rule for calculating lever powers (25).

Figure 19.

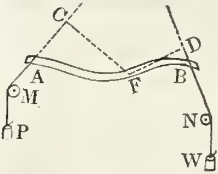
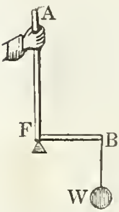


Figure 20.



62. Sometimes the lever is bent in such a manner that the long arm rises perpendicularly from the fulcrum, as in figure 20. In this case, the upright long arm from F to A acts precisely as if it were horizontal, because the power or hand is supposed to act at right angles to the arm. If we were to draw an ideal line from the top of the arm at A directly downwards to F, it would descend straight through the arm, and hence, in this case, there would be no use in drawing it. The calculation may be made with the arm itself.

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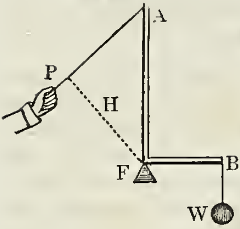
61. What of ideal levers, and their uses?
62. Explain each of the diagrams.

Figure 21.



63 But if the power be made to draw obliquely downward, or not at right angles to the line from the fulcrum, we must draw an ideal line, as represented in figure 21. The line of direction of the power is seen proceeding obliquely from A to the hand P. A dotted line H is drawn at right angles from this line to F the fulcrum; the line H therefore represents the true arm of power of the lever.

64. Suppose the line of direction of the power in the last figure, had been drawn slantingly upward instead of downward, then an ideal dotted line would have heen to be drawn obliquely downward from it, crossing the arm at A, and a line drawn at right angles from it to F, would have represented the arm of power.

Figure 22.

65. The adjoining figure, representing a pronged hammer in the act of being employed to extract a nail, is an example of a bent lever, resembling those just mentioned. The hand of the workman is the power exerted on the long arm of the lever; the head of the hammer, where it presses on the flat surface beneath it, is the fulcrum; the prongs are the short arm of the lever, and the resistance of the nail is the weight.

66. From the examples now given, it will be observed that, whatever be the shape or bending of the lever, and whatever the degree of obliquity of the applied force, the power of the machine may be calculated by drawing ideal lines at right angles from the lines of the forces to the fulcrum, and making the calculations from them.

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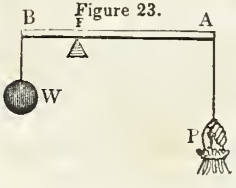
63. How are calculations made in all cases?

RECAPITULATION OF LEVER POWERS, AND ANIMAL LEVERS.

67. To avoid confusion or misapprehension, representations of the three kinds of levers already defined are here again exhibited, along with a few brief explanatory observations on their character and comparative value. For the sake of clearness, a hand pulling is substituted as the power. The *arm of the power* is used to signify the long arm, and the *arm of the weight* the short arm.

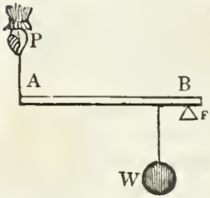
68. Each of the three kinds of levers has its own special advantages, and is peculiarly adapted to certain situations and purposes. In a lever of the first kind, where the point of support is between the power and the weight, either the power or the weight may have the advantage. The advantage varying thus between the power and the weight, the lever of the first kind is held to be most convenient for an equilibrium; of which, as has been shown, the common balance affords an example.

Figure 23.



69. In the lever of the second kind, the arm of the power is necessarily longer than that of the weight or resistance, since the resistance is between the power and the fulcrum, whilst the power is at one extremity. The advantage being thus always in favour of the power, the lever of the second description is always favourable for overcoming resistance.

Figure 24.



70. In the lever of the third kind, on the contrary, the advantage is in favour of the weight or resistance, which is placed at an extremity, while the power lies between it and the point of support. But the disadvantageous position

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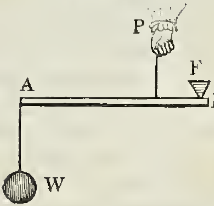
64. What kind of lever is shown in each diagram ?
65. Name the advantages and uses of each kind.

of the power in this kind of lever is compensated by the extent of motion which necessarily ensues from that very disadvantage; for, the closer the power is to the fulcrum, and the farther it is from the weight, the more extensive and rapid is the motion to which the weight can be subjected on the slightest action of the power. The lever of the third kind, therefore, is obviously favourable to extensive and rapid movements.

Figure 25.



ANIMAL LEVERS.

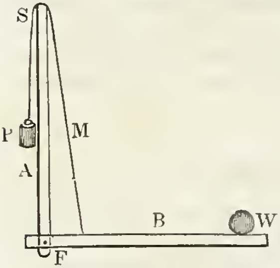
71. A short consideration of the characteristic advantages and defects attendant on each of the three kinds of levers, will suffice to convince us of the superior applicability of the third kind of lever to the purposes of animal motion. Celerity and extent of motion, it is obvious, are here objects of paramount importance; and by the employment chiefly of this species of lever, both in the trunk and the limbs, they are beautifully and effectually attained. In the animal machine, the bones form the bases or *arms* of the levers; the muscle, contractible at the command of the will or fancy, represent the *power;* the joints, the *fulcrums* or points of support; and the weight of the body or of individual limbs, as it may happen, constitutes the *weight* or resistance, increased, as in the case of the hands at times, by some substance carried or held by them. The most important result of the lever powers of the animal machine, is locomotion, or the transmission of the whole body from place to place. [In human structure, as indeed in all animal organization, it is wonderful to observe the mechanism o' the Creator's wisdom and goodness, anticipating all the boasted discoveries of science, and plainly teaching the highest lesson in practical and experimental philosophy.]

72. The spinal or vertebral column, when we regard its

66. What of the bones, muscles, and joints of animals?

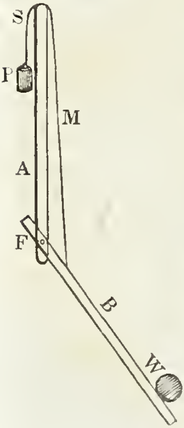
motions as a whole, represents a lever of the third kind, of which the fulcrum is in the articulation of the last bone of the column with the *sacrum* (the bone on which the trunk rests); the power being in the muscles, which are inserted into the vertebral column along its course, and the resistance in the weight of the head, neck, and trunk.

Figure 26.



73. But a much more distinct and intelligible example of a lever of the third kind in the animal frame, is exhibited in the human arm. A strong muscle, arising in the shoulder, passes down in front over the joint of the elbow, and is inserted into one of the two parallel bones which compose the frame work of the fore-arm, or from the elbow to the wrist. On being contracted in the slightest degree, at the impulse of the will, this muscle (the *power*) elevates instantaneously the hand (the *weight* or resistance) to the shoulder, bending the arm upon the elbow-joint, (the *fulcrum*). Figure 26 illustrates perfectly this mechanism of the arm. F represents the elbow-joint, P the power or will acting over, or from the shoulder S, through the contracting muscle M, and B the arm from the hand to the elbow, while the weight W, is an object supposed to be laced in the hand.

w . Figure 28



74. Nothing can better illustrate the characteristic advantages of levers of the third kind, than this action in the human arm. The contraction of the muscle to the extension of only one inch, raises

67. What of the spinal column?
68 Explain the diagram mechanically.
69. What does this diagram show?

the hand, even with a very considerable weight in it, through a semicircle of twenty-one inches; and by relaxing the muscle only a little, the hand, as represented in figure 27, is allowed to drop over a similarly wide range. No doubt, other muscles in the arm assist in this action, but the principal part is performed by the one described, and here indicated by the letter M.

75. It is worthy of observation, that in the second of these figures, illustrating the mechanism of the arm, the lever power acts under increased disadvantage from the greater inclination of the limb than in the preceding figure. We can raise or sustain a much larger weight with the hand when the arm is bent at right angles, than when it is extended nearly in a straight line; and the more the arm is stretched out, the more is the power diminished. What is gained, however, in force, is necessarily lost in extent of motion.

76. A fine example in the animal frame of the lever of the third kind, where extent of motion was not the object wanted, as it is in the arm, is seen in the mechanism of the lower jaw. To overcome resistance, was in this case the chief end required; and, accordingly, we find a strong muscle constituting the power, passing perpendicularly downwards from the side of the head to the lower jaw-bone, and acting on it in a straight line, the fulcrum being in the articulation of the jaw near the ear. The force with which the power acts in this case is immense, particularly when the resistance to be overcome is placed near the fulcrum, or directly beneath the action of the muscle. We take advantage of this circumstance in cracking nuts, by putting them to a certain distance back between the jaws.

77. As in the arms, so also in the inferior extremities, the principal muscles hold such a relative position to the bones and joints, as to sustain the weight of the body, and transfer it along the surface of the ground, with all the advantage of a lever power of the third kind. If the mechanical action of the muscles and bones in animals, whether in the spinal column or in the limbs, had been arranged

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70. What of the muscle of the jaw?

on the principle of either of the other descriptions of levers, the requisite contraction in the length of the acting muscles would have been so great as to render the shape of the limbs, and the whole figure indeed, extremely clumsy, and the movements very inconvenient; and hence the wisdom of the existing arrangement, in regard to simplicity, beauty and efficiency.

78. Examples of the first and second kinds of levers are not absent in the animal machine; and where such examples occur, they uniformly corroborate what has been said respecting the peculiar character of each of the three kinds of levers. The head, for instance, requires, for the fulfilment of its exalted uses, and for the comfort of the being, to be maintained erect, and in equilibrium. A lever of the first kind, we have seen, is the one best calculated to effect this object, and accordingly, such a mechanism is found to exist here. The point of support of this lever is in the articulation of the lateral masses of the two first bones of the spinal column, whilst the power, and the resistance or weight, occupy each an extremity of the lever, represented, the one by the face, and the other by the back part of the head. To understand this fully, it must be explained, that the point of support, or *fulcrum*, on which the head rests, is much nearer to the back part of the skull than to the fore part or face; therefore, this forepart (the *weight* of the lever) has a tendency to fall forwards, but is retained in equilibrium by the strong muscles passing from the lower parts of the neck to the hind part of the head (which is thus rendered the site of the power of the lever.) A perfect lever of the first kind is thus made the agent in maintaining the head in equilibrium.

79. In like manner, it might be shown, that, where there is a considerable resistance to be overcome, the bones and muscles are so arranged as to represent a lever of the kind best calculated for the fulfilment of such a purpose—namely, a lever of the second kind, as the first is employed when an equilibrium is to be maintained, and the second when rapid and extensive motion is to be produced.

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71. Would either of the other kinds of levers have been as well?
72. What example of the first kind of lever is cited?

OF THE WHEEL AND AXLE.

WHEELS.

80. A lever has been defined, (10) to be "a rod or bar of iron, wood, or any other material which is moveable upon or about a prop or fulcrum, or about a fixed axis."

81. The illustrations which have been given, show the lever only in its character of a simple bar, which is moveable in some part "upon or about a prop or fulcrum." It is now to be shown how it acts when moveable upon or about a fixed axis.

82. When a lever is moveable upon an axis, and is susceptible of being turned completely round, it assumes the character of the diameter of a wheel.

83. In figure 28, the simple rudiments of a wheel are represented. A and B are the two arms of a bar or lever playing upon a fixed axis at F, and which axis is the fulcrum. If we push down A, we raise B, or if we push down B, we raise A. In this manner the situation of the power and the weight is transferable from one end to the other, as in the beam of a common balance, without altering the equilibrium.

Figure 28.

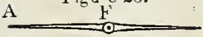
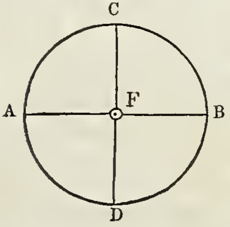


Figure 29.



84. Figure 29 is a representation of a wheel in a state more advanced to completion. Here the arms AB are connected with the arms DC, both at the centre F, and by means of the circumference or rim of the wheel. By reason of this union of parts, the central axis at F becomes the common fulcrum for every portion of the wheel; therefore, from the centre to any point of the circumference is an arm of a lever, although the line of that lever be not marked or seen, as in the case of a distinct spoke.

85. A line through the centre from one side of the cir-

73. What of the wheel and axis?
74. Explain the diagrams.

cumference of a wheel to the opposite side, is the diameter; from the centre to any part of the circumference, is the semi-diameter or radius. The arms or spokes are said to radiate from a centre. The circumference is sometimes called the periphery.

86. Besides wheels with axes in the centre, there are wheels with axes not in the centre, called eccentric wheels. At present, however, we are treating only of wheels having their axes in the centre.

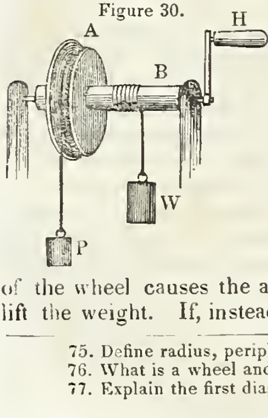
87. Wheels with a central axis may be rendered available as levers in various ways, according to the placing of the weight or resistance. The plan commonly pursued consists in giving to the wheel an axle, which is fixed to its arms, and placing a weight near the axle or fulcrum, to work against another weight at the circumference.

88. Thus, a machine is formed called the Wheel and Axle, which constitutes one of the simple mechanical powers, founded on the lever.

WHEEL AND AXLE.

69. The machine termed the Wheel and Axle consists of a wheel fixed upon an axle or spindle, which axle turns horizontally on its two ends in upright supports. See figure 30. The fulcrum of the machine is common to both the wheel and the axle, and is the centre of the axle. A is the wheel, B is the axle, and H is a handle with which the machine may be turned. By turning the wheel, the axle is also turned, and a rope being fixed to the axle, with the weight W hanging at its extremity, the turning of the wheel causes the axle to wind up the rope, and so lift the weight. If, instead of turning the wheel with the

Figure 30.



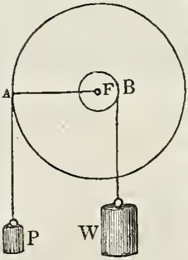
75. Define radius, periphery, and eccentric wheels.
76. What is a wheel and axle ?
77. Explain the first diagram.

hand, we wind a rope round the circumference of the wheel, in a contrary direction from that in which the axle rope is wound, and also hang a weight of a certain heaviness, P, to its extremity, then the draught or pulling of the wheel rope in unwinding, will turn the axle, and so wind up the axle rope with its weight. In this manner, one power works against another, exactly as in the case of the lever. By properly apportioning the two powers in correspondence with the diameters of the wheel and the axle, the one power or weight may be made to balance the other power or weight, so as to produce an equilibrium of the machine.

90. The wheel and axle form what is called a PERPETUAL LEVER. Common simple levers act only for a short space, or by reiterated efforts, so as to be adapted for lifting an object from one place to another on the ground. The perpetual lever, formed by the wheel and axle, turns round without intermission, and is therefore suitable for lifting weights attached to a rope, through a considerable space upward from the ground without stopping.

91. Figure 31 is a representation of the machine endwise, and shows how the lever operates. The line going across the machine from A to B represents the line of the lever. A is the situation of the power, F is the centre or fulcrum, and B is the situation of the weight; therefore, from A to F is the long arm, and from F to B is the short arm of the lever. In other words, the long arm is half the diameter of the wheel, and the short arm is half the thickness or diameter of the axle.

Figure 31.



92. By widening the wheel, and so lengthening the long arm of the lever, the smaller will be the power necessary to overcome the weight on the axle or short arm; but what is gained by this mechanical advantage is lost by the circumstance that the power must descend through a proportionally greater space in order to raise the same

78. What is the use of the second?
79. How is this shown to be a modification of the lever?

weight through the same space in the same time. This is in agreement with the principle mentioned in paragraph 17.

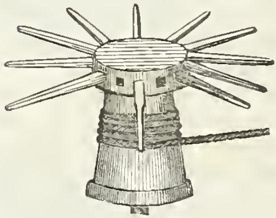
93. To find what forces will balance each other, let the same rules be followed as those given for the simple lever in paragraph 25. Multiply the weight by its distance from the fulcrum (that distance is half the diameter of the axle); then multiply the power by its distance from the same point (that is, half the diameter of the wheel), and if the products be equal, the weight and the power will balance each other. Thus, a power of one pound at or depending from the circumference of a wheel of twelve inches in diameter, will balance a weight of twelve pounds at or depending from the circumference of an axle one inch in diameter.

Note. No allowance is made in these calculations for the overlaying of the rope in winding, which affects the length of both the long and short arm; but this is a matter of practical, not of theoretic import.

94. The principle of the wheel and axle, or perpetual lever, is introduced into various mechanical contrivances which are of great use in many of the ordinary occupations of life. One of the simplest machines constructed on this principle, is the common windlass for drawing water by a rope and bucket from wells. Coal is lifted from the pits in which it is dug, by a similar contrivance, wrought by horse or steam power.

95. The capstan in general use on board of ships for hauling or drawing up anchors, and for other operations, is an example of the wheel and axle, constructed in an upright or vertical, instead of a horizontal, position. In figure 32, one of these capstans is represented. The axle is placed upright, with the rope winding about it, and having a head pierced with holes for spokes

Figure 32.



80. By what rule are the forces calculated?
81. What examples are cited?

or levers, which the men push against to cause the axle to turn. This is a powerful and convenient machine on shipboard; when not in use, the spokes are taken out and laid aside.

An illustration of the wheel and axle, in a combined form, is afterwards given in the case of the crane.

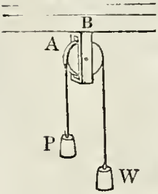
OF CORDS AND PULLEYS.

96 The pulley, or cord, is one of the primary mechanical powers. A pulley is a wheel, with a groove in its circumference, and is suspended by a central axis. In fixed pulleys, a flexible cord, which is made to pass over and hang from the upper part of the groove, has at one extremity a certain weight to be raised, and at the other extremity a power is attached for the purpose of pulling.

97. There are two kinds of pulleys, the fixed and moveable.

FIXED PULLEYS.

Figure 33.



98. The annexed cut, figure 33, represents a fixed pulley. A is the wheel; B is a beam or roof from which the wheel is suspended. P is the power hanging at one end of the rope, and W is the weight at the other end. This kind of pulley is called a fixed pulley, because it does not shift from its position.

99. The fixed pulley possesses no mechanical advantage. The wheel is merely a lever with equal arms, and therefore the cord which passes over these arms gains no advantage. To raise a pound weight from the ground at the one end of the cord, the power of one pound must be exerted at the other.

100. The object of the single fixed pulley is not to save

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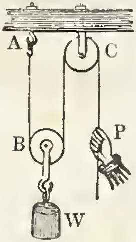
82. Define a pulley, and how many kinds.
83. Explain the first diagram.
84. What advantage is gained by a fixed pulley?

power, but to give convenience in pulling. For instance, by pulling downwards, a weight may be raised upwards, or by pulling in one direction, a load may be made to proceed in another. The same object might be gained by drawing a cord over a fixed post or pivot, but in this case the friction of the cord would chafe or injure it; the wheel or pulley is therefore a simple contrivance to prevent friction, for it turns round along with the cord.

MOVEABLE PULLEYS.

101. The moveable pulley is in form the same as the fixed pulley, but instead of being placed in a fixed position from a beam or roof, it hangs in the cord which passes under it, and from it the weight is suspended. In figure 34, a moveable pulley is represented. A is a hook in a beam to which one end of a cord is fixed. B is the moveable pulley, under which the cord passes and proceeds upwards to C, a fixed pulley, from which it depends to P, the power or the hand pulling. The fixed pulley C is of no further use than to change the direction of the power. W is the weight hanging from B.

Figure 34.



102. The moveable pulley possesses a mechanical advantage. The first point to be observed is, that the weight hangs in the cord; second, that the weight presses down each side of the cord equally—that is, it draws as hard at A as at C or P; third, that the consequence of this equal pressure, is the halving of the weight between the two ends of the cord. The HALVING OF THE WEIGHT is therefore the mechanical advantage, given by the moveable pulley.

103 EXAMPLE.—If the weight W be ten pounds, five pounds is borne by A, and five pounds by P. The case is precisely the same as that of two boys carrying a basket between them. The basket is the weight, and each boy,

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85. Explain the moveable pulley and the diagram.
86. In what does the advantage consist?

with his hand upholding the handle, bears only half the load, whatever it may be. If, instead of holding by the handle, the boys slip a cord beneath it, and each take an end of the cord, the case is the same.

104. In order to save expenditure of power in lifting weights by pulleys, it is always contrived to cause some inanimate object, as for instance a beam or roof, to take a share of the weight, leaving only a portion to be borne by the person who pulls. But in this as in all cases of mechanical advantage, the saving of power is effected only by a certain loss of time, or a longer continuation of labour. To lift a weight one foot from the ground, by the moveable pulley a man must pull up the cord two feet: therefore to lift a weight, it will take double the exertion to draw it up a given height in a given time without the pulley, that it would require with the intervention of the pulley.

Figure 35.

105. As the power which a man can exert by his hands, is able to overcome a weight greater than the weight of his own person, this circumstance may be taken advantage of in a very peculiar manner, through the agency of the fixed pulley. As represented in figure 35, a man may seat himself in a loop or seat attached to one end of a cord, and passing a cord over a fixed pulley above, may pull himself upwards by drawing at the other end of the cord. By adding a moveable pulley and another fixed pulley to the apparatus, the exertion of pulling would be diminished one half. An apparatus of this nature having two fixed pulleys and one moveable pulley, is used by house masons and other artizans, in making repairs on the fronts of buildings.

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87. What illustrations are given?
88. Explain the diagram.
89. How may the exertion be diminished?

PRINCIPLE OF THE PULLEY POWER.

106. The principle upon which pulleys act, is the distribution of weight throughout the different portions of the cord, so as to lessen the power necessary to be exerted by the operator. And along with this principle is the changing of the direction of the power for the sake of convenience in pulling.

107. According to ordinary language, the mechanical power of which we are treating, is called the power of the pulley; but, in reality, as has been just shown, the pulley has no power in itself. The power of the machine is in the cord. IT IS THE EQUAL TENSION OF THE CORD THROUGH ITS WHOLE LENGTH, BY WHICH THE WEIGHT IS DISTRIBUTED UPON INTERVENING POINTS, THAT THE MACHINE OFFERS ANY MECHANICAL ADVANTAGE.

108. In all cases in which cords are drawn tightly, so as to hold objects in close contact, the same species of power or mechanical advantage is exemplified. For instance, in drawing a cord in lacing, or a thread in sewing, this distribution of power is observable. If all the power which is distributed throughout the sewing of a single pair of strong shoes, were released and concentrated in one main draught, it would, in all likelihood, be a power sufficient to lift one or two tons in weight.

109. Technically, the wheel of a pulley is called a *sheave;* for protection and convenience this sheave is ordinarily fixed with pivots in a mass of wood called a *block;* and the ropes or cords are called a *tackle.* The whole machine fully mounted for working is termed a *block and tackle.* By causing a wheel and axle to wind up the cord of a block and tackle, the power of the lever is combined with that of the pulley in the operation.

110. There is no assignable limit to the power which

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90. Explain the principle of the pulley.
91. Where is its power found ?
92. Name the illustrations of this power.
93. Define sheave, block and tackle.
94. What is said of the limit of this power?

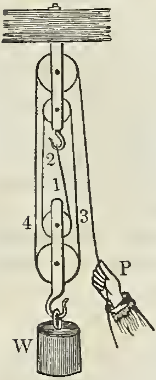
may be exerted by means of pulleys. The machine may be constructed to raise with ease any weight which the strength of materials will bear, provided the combination is not so complex as to exhaust the power by the friction produced.

111. The power of pulleys is increased by a combination of wheels or sheaves in one tackle. There are different kinds of combinations or systems of pulleys. In some there is only one fixed pulley, and in others there are several.

COMBINATIONS OF PULLEYS.

The following are examples of different combinations of pulleys:—

Figure 36.



112. Figure 36 represents a compound system of pulleys, by which the weight is distributed through four folds of the same cord, so as to leave only a fourth of the weight, whatever it may be, to be raised by the operator. In this illustration, the cord number 1 bears one fourth of the weight: the cord number 2 bears a second fourth; the cord number 3 bears a third fourth; and the cord number 4 bears a fourth fourth. Here the mechanical advantage ceases. For, although the cord number 4 passes over the topmost fixed pulley down to the hand of the operator, no more distribution of power takes place; this topmost pulley being of use only to change the direction of the power. The person who pulls has thus only a quarter of the weight to draw. If the weight be one hundred pounds, he has the labour of pulling only twenty-five pounds.

113. Thus it is observable that the diminution of weight is in proportion to the number of moveable pulleys. To

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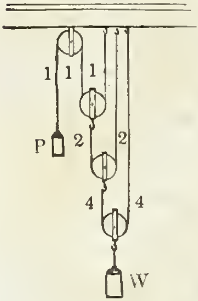
95. How may it be increased?
96. Explain the first diagram.
97. How is the power calculated?

calculate the expenditure of power or diminution of weight, therefore, we have only to multiply the number of moveable pulleys by two, and the product shows the power to be exerted. Two moveable pulleys multiplied by two, gives 4; therefore a fourth of the weight is the power required, and so on. The addition of a single moveable pulley to any system of pulleys, at once lessens the apparent weight one half, or, in other words, doubles the effect of the power; but every such addition causes more time to be spent in the operation, there being at every additional fold of the cord more cord to draw out, and also more friction to overcome.

Figure 37.



114. In the annexed system of pulleys, figure 37, a series of moveable pulleys, with different cords, are made to act successively on one another, and the effect is doubled by each pulley. At the extremity of the first cord a power of one pound depends. This cord, marked 1, by being drawn below a moveable pulley, supports 2 pounds —that is 1 pound on each side. The next cord marked 2, in the same manner supports four pounds, or 2 pounds on each side. The next cord marked 4 supports eight pounds, or four pounds on each side. Thus 1 pound at P, supports 8 pounds at W. If another moveable pulley were added, the 1 pound at P would support 16 pounds, and so on.

115. In working pulleys, the power must be applied in a line perpendicular to, or parallel with, the weight; that is, straight above the weight, in order to produce the full efficacy of direct force. If the power be applied obliquely —do not draw fair up—there will be a loss of power in proportion as the line of draught departs from the perpendicular.

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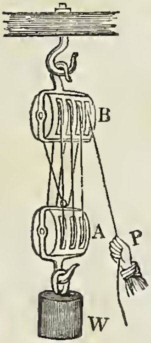
98. What of the next diagram?
99. What of oblique action?

PRACTICAL APPLICATION OF PULLEYS.

116. Pulleys are used chiefly on board of ships, where blocks and tackle are in constant requisition for raising and lowering the sails, masts and yards. They are likewise in considerable use by house-builders and others, in connection with the wheel and axle, for raising or lowering heavy masses of stone and other articles.

Figure 38.

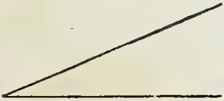


117. Figure 38 is a representation of a system of pulleys commonly used in practical operations. Three moveable pulleys are inclosed in the block A, and three fixed pulleys are inclosed in the block B. . Suppose, therefore, that the weight W in this case, is six hundred pounds, the hand P pulls it upwards by exerting a force of only one hundred pounds. A combination of pulleys resembling this is used in turning kitchen jacks. The weight in sinking draws off the cord from a spindle, by which motion the jack is turned. In order that a considerable weight falling slowly through a comparatively small height may keep the jack in motion for a long time, as many as ten or twelve moveable and fixed pulleys are used.

OF THE INCLINED PLANE.

118. A horizontal plane is a plane coinciding with that of the horizon, or parallel to it; when the plane is not level or horizontal, but lies in a sloping direction, with one end higher than the other, it is said to incline, or is called an inclined plane. Figure 39 is an example.

Figure 39.



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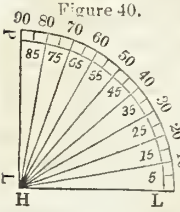
100. Name the uses of this power.
101. Explain the diagram.
102. What of an inclined plane ?

STANDARDS OF COMPARISON FOR INCLINATIONS.

119. The inclination of a plane may be to any extent, from that of a slight rise off the horizontal to almost an upright or perpendicular ascent. For the sake of convenience in language, the extent of the inclination is defined by comparing it to the numbers of degrees in a quarter of a circle. A circle being divided by mathematicians into 360 degrees or parts, the quarter of the circle includes ninety degrees. Taking, then, a quarter of a circle, and marking it, as in figure 40, H L is the horizontal line, and P L is the perpendicular line ascending from it. Any line drawn from the centre to any point on the circumference defines the degree of inclination. Thus, a line ascending from the centre to the 10th degree is called an *inclination* or *angle of ten degrees;* a line ascending to the 45th degree is called an *inclination* or *angle of forty-five degrees;* and so on with all the other degrees, to the 90th. In this manner a standard of comparison has been established for defining the various slopes or inclinations in planes.

Figure 40.



120. Another standard of comparison for slopes consists in referring the rise to so many feet in a certain length or distance—as for instance, a rise of one foot in ten feet, a rise of one foot in twenty, a rise of so many inches in a mile, and so on.

121. In the case of inclinations of hills, or other elevations composed of loose matter, there is a certain degree of sloping, which will permit the materials to remain at rest, and not slide or roll down in obedience to the law of gravitation. The degree of inclination at which the particles of matter remain at rest, just before they would slide down, is termed the *angle of repose.* This angle is, of course, different in different kinds of bodies.

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103. What variety of inclined planes and how described?
104. Explain the diagram.
105. What other standard is used?

PRINCIPLE OF THE POWER OF INCLINED PLANES.

122. The inclined plane, as already stated, is a primary mechanical power. The object which is accomplished by it is the raising of weights to considerable elevations, or the overcoming of resistances by the application of lesser weights and resistances; or, making a small power overcome a greater.

123. To raise a load of a hundred pounds to an elevation of fifty feet by a direct perpendicular ascent, and without using any mechanical advantage, the power exerted must be a hundred pounds, or equal to the weights to be overcome. If, instead of raising the load directly upwards, we raise it by the gradual ascent of an inclined plane, the power required is less than a hundred pounds, and the diminution is in proportion to the smallness of rise in the inclined plane. But this saving of power, as in all other instances of mechanical advantage, is accomplished only by a corresponding loss of time.

124. In drawing a load, as, for instance, a loaded carriage, along a horizontal plane, the resistance to be overcome is chiefly the friction of the load upon the plane. If there were no friction or impediment from inequalities of surface, and if the load were once put in motion, it would go on moving with the smallest possible expenditure of power.

125. In drawing a load up an inclined plane, ordinary friction has to be overcome, and also the gravity of the body, which gravity gives it a tendency to roll down to the lowest level. In this constant impulse to descend, it is not at liberty to pursue the same line of descent as bodies falling freely from heights. It falls or rolls down as much less speedily than a free falling body (omitting the loss by friction) as the length of the inclined plane is greater than its height. A freely descending body falls about 16 feet

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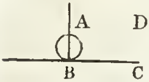
106. What mechanical objects are thus gained?
107. Name the illustration here cited.
108. What resistance has to be overcome?

in the first second; and a body rolling down an inclined plane, rolls just as many feet the first second as the number of feet of inclination is in sixteen feet. If the inclination be one foot in sixteen, the body rolls down one foot, and so on.

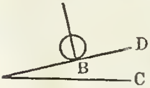
126. Any body in being drawn up an inclined plane, by a power parallel with the plane, presses at right angles with the plane. The common expression is, that the reaction of the plane upon the object is perpendicular to the plane.

Figure 41.



When an object, as a ball, rests upon a horizontal plane, its pressure is at right angles with the plane; or what is the same thing, the reaction or resistance of the plane is at right angles with it. This is seen in figure 41, in which a ball is represented lying on a level plane, with the line of pressure A passing down to B, which line is at right angles with the plane. Suppose, then, that the end of the plane at C is elevated to D, as in figure 42, so as to form a slope; in this case the line of pressure of the ball on the plane is also moved. so as still to be at right angles with the inclination.*

Figure 42.



127. The power which is required to be sustained for the purpose of overcoming friction or inequalities of surface on level planes, is for the purpose of drawing the load up or over the inequalities.

RULES FOR CALCULATING THE POWER OF INCLINED PLANES.

128. The amount of the power corresponding to different weights and inclinations of the plane has been correctly ascertained, and the following are the rules upon the subject:—

129. First.—The quantity of weight is great in proportion to the inclination of the plane; consequently, so is the

* This proposition is proved by a mathematical demonstration which it is thought inadvisable to introduce here. The question is one of Resolution of Forces, and is treated of in works for advanced students.

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109. What of the ratio of descent?
110. Explain the diagrams.
111. How is the power of inclined planes calculated?

difficulty of raising greater, and the rate of elevation or motion slower.

130. Second.—To overcome the weight or resistance, and the slowness of movement, a corresponding increase of power must be given.

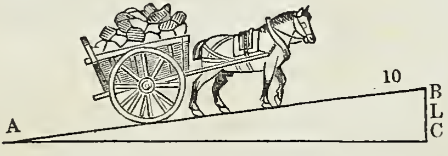
131. Third.—The smaller the inclination, so is the pressure of the weight on the plane the greater.

132. Fourth, or special rule of calculation.—Whatever is the unit of inclination in a given length, the same is the unit of weight that can be lifted, and the unit of power to be exerted.

EXAMPLES.

133. If the inclination of a road be *one* foot in ten, *one-tenth* is called the unit of inclination; hence, *one-tenth* part of the nominal weight of the load has to be lifted; and a power to draw this one-tenth part of the load has to be exerted. Or, to put the case in other words:—If the road rise one foot in ten, there is in the ten only one foot of perpendicular height to be lifted through; and the weight at any point of the ten feet is only a tenth of what it would be if it were to be lifted through a perfect perpendicular ascent of ten feet. This is exemplified in figure 43, in

Figure 43.



which a loaded cart is in the act of being drawn up an inclined plane of ten feet in length, having a rise of one foot throughout its extent, that is, from A to B. This rise of one foot is marked at the end of the plane, from C to B. Although, therefore, the cart has to be pulled a distance of ten feet, it in reality is pulled *upwards* only one foot, and

112. What is the unit of inclination?
113. Explain the diagram, and its principle.

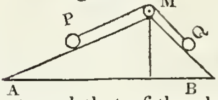
the horse which draws has the advantage of pulling only one-tenth.

134. The reason is now perceived why a small power overcomes a greater in the case of draughts upon inclined planes. The load is, as it were, lifted by instalments. Partly supported as it advances, and always supported more completely the smaller the inclination, the weight of the burden is apparently lessened by merely taking the rise gradually and slowly.

135. If we suppose a case of two roads, the first rising one foot in twenty, and the second rising one foot in fifty, a loaded carriage will be found to go over the fifty feet of the one with precisely the same expenditure of power that would be required to make it go over the twenty feet of the other—that is, always providing that friction and other circumstances are alike.

136. Figure 44 represents a supposed case of two inclined planes of the same height, but different slopes, meeting together at the top, with a weight resting on each, P and Q, hanging by a string, which passes over the pulley M. If the length of the longest plane from A to M be two feet, and that of the shorter from B to M be one foot, then two pounds at Q, on the short side, will balance four pounds at P, on the long side; and so on in this proportion, whether the planes be longer or shorter.

Figure 44.



137. In this manner, weights moving on two adjoining inclined planes may be adjusted so as to balance each other, although the inclinations be different; and they are so made to act on various sloping railways connected with public works, where one wagon descending on one plane is made to draw up another wagon on another plane.

138. An inattention on the part of our forefathers to these exceedingly simple principles of mechanical science, led them to form roads over steep hills, pursuing, as it was

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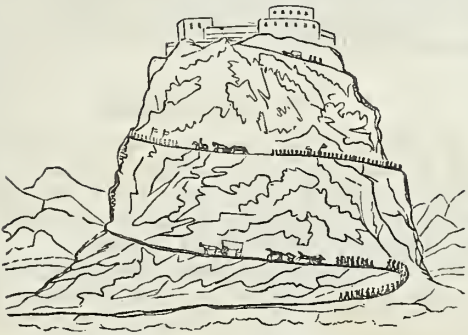
114. How may expenditure of power be estimated ?
115. Explain the first diagram.
116. How are inclined planes used on rail ways.

Figure 45.



magined, the best routes, because they were the straightest in a forward direction. In modern times, this error has been avoided by enlight ed engineers, and roads are now constructed with as few risings and fallings as possible. When roads have necessarily to be carried to the summits of heights, they are very properly made either to wind round the ascent, or to describe a zig-zag line of direction. Figure 45 represents a road pursuing a winding direction round a hill on which a fort is planted.

139 The drivers of carts are aware of the saving of labour to their horses by causing them to wind or zig-zag up steep roads instead of leading them directly forward.

140. The inclined plane is resorted to for a saving of labour in many of the ordinary occupations of life. By it, loaded whéel-barrows are with comparative ease wheeled to considerable elevations in house building and other works of art; hogsheads are rolled out of or into wagons, and ships are launched into or drawn from the water, the inclined plane being as useful in giving facilities for letting down loads as in drawing them up.

141. It is also by inclined planes that we reach the higher floors of a house from the ground, or attain other

117. Explain the second diagram.
118. Name some of the practical uses of inclined planes.

elevations. For all such purposes, the inclined plane is formed with steps to insure our safe footing. All stairs or flights of steps are inclined planes. A ladder forms a steep inclined plane.

OF THE WEDGE.

142. The inclined plane has been described as being fixed or stationary, as, for instance, a common ascending road, or a sloping plank, upon which the weights are moved. It has now to be viewed as a *moveable plane,* in which form it suits many useful purposes.

143. When an inclined plane is moveable, and the load or weight which it affects is at rest, it receives the name of a Wedge. The wedge is, therefore, a mechanical power, founded on the principle of the inclined plane.

144. The Wedge is an instrument or simple machine, consisting of a solid body of wood, iron, or some other hard material, and is triangular in form. See figure 46. Here the wedge is seen to taper from a thick end or head at B to a thin edge or point at A. This, however, is only the more common form of the wedge. It is made with sides of various angularities or degrees of slope; and, in some cases, it possesses a flat and a sloping side, as in figure 47. When it slopes on both sides, it consists of two inclined planes joined together; and when one of its sides is flat, as in figure 47, it acts as only one inclined plane.

Figure 46.

Fig.47.

145. The wedge is employed as an instrument for cleaving solid masses asunder, to compress bodies more closely together, and to move weights through small spaces. Figure 48 is a front view of a wedge in the act of splitting asunder a piece of timber. The power employed to force the wedge forward, is either repeated blows with a mallet or hammer, or the gradual

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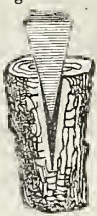
119. What of a moveable plane?
120. Explain the diagram.
121. What of the varieties and uses of the wedge.

Figure 48.



pressure of a weight. In general, the power is applied by rapid strokes, or quick applications of some kind of external pressure.

RULES FOR CALCULATING THE POWERS OF THE WEDGE.

146. The rules for calculating the power of the wedge are similar to those for the inclined plane. In proportion as the inclination or angularity is great, so is the resistance greater, and the power must be greater to overcome it. Thus, if the wedge be of short dimensions and thick at its head, it will require a greater power to move it than if it be long and thin in its form.

Figure 49.

147. The resistance offered to the wedge of equal sides, when the pressure is equally applied, is, as in the case of the inclined plane, at right angles with the sides. See figure 49, in which the oblique cross lines represent the direction of the pressure passing at right angles through the sides, and meeting at the centre.

148. It is difficult to calculate the precise power of the wedge, for much depends on the force or the number of blows which may be given it, together with the obliquity of the sides, and the power of resistance in the object to be split In the splitting of timber, for instance, the divided parts act as levers, and assist in opening a passage for the wedge.

EXAMPLES OF WEDGE POWERS.

149. The wedge is the least used of the simple machines, but the principle upon which it acts is in extensive application. Needles, awls, bodkins, and driving-nails, are the most common examples. Knives, swords, razors, the axe, chisel, and other cutting instruments, also act on the prin-

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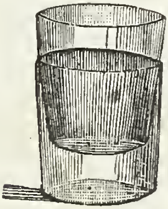
122. By what rules are the power of wedges calculated ?
123. What common examples are cited ?

ciple of the wedge; so likewise does the saw, the teeth of which are small wedges, and act by being drawn along while pressed against the object operated upon.

150. The principle of the inclined plane, which is the basis of that of the wedge, is particularly observable in the action of the razor and the scythe, both of which cut best by being drawn along the materials against which they are applied. When the edge of a scythe or razor is examined with a microscope, it is seen to be a series of small sharp angularities of the nature of the teeth of a saw.

Figure 50.



151. The principle of the wedge operates in the case of two glass tumblers, one placed within the other, as in figure 50. A very gentle pressure applied to the uppermost tumbler would be sufficient to burst the lower. At every little advance of the uppermost tumbler, it acts more and more as a lever power on the rim of the lower, and at last overcomes the resistance, and fractures the vessel.

OF THE SCREW.

152. The screw is the fifth, and usually the last-mentioned mechanical power. Like the wedge, it is founded on the principle of the inclined plane.

Fig. 51.

153. The screw consists of a projecting ridge winding in the form of an inclined plane, and in a spiral direction, round a central cylinder or spindle, similar to a spiral road winding round a precipitous mountain. Figure 51 is a representation of a common strong screw used in various mechanical operations. The projecting ridge on the spindle is technically called the *thread*. The thread is not always made in this square projecting form; it is frequently sharpened to a single thin edge, as in figure 54, but this does not affect the principle of the machine.

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124. What of a microscopic inspection of a razor or scythe?
125. Explain the first diagram.
126. What is the principle of the screw?
127. Explain the diagrams, and the italicised terms.

154. One circumvolution or turn of a thread of a screw is, in scientific language, termed a *helix* (plural *helices*), from a Greek word signifying winding or wreathing. The spiral winding of the thread is called the *helical line.*

Fig. 52.

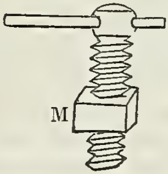
155. The helices of a screw do not necessarily require to have a central spindle. They may form a screw of themselves, and do so in the case of the common cork-screw. Figure 52. A screw of this pointed or tapering form, in penetrating a substance, possesses the advantage of the inclined plane in three ways; first, by the gradual thickening of the substance of the thread from a sharp point; second, the gradual widening, and third, the gradual ascending, of the thread.

POWERS OF THE SCREW.

156. The screw acts on the principle of the inclined plane, and this is obvious from the consideration of the nature of the threads. If we were to cut through the turns of the threads straight from top to bottom, and draw them out to their full extent, each separate and retaining its own inclination, we should find that they were so many inclined planes. In the annexed cut, figure 53, one entire turn of the thread is thus drawn out, reaching from *b* to *a*, and is seen to form an inclined plane. If not drawn out, it would wind down to *c*; therefore, while a weight is raised by one turn of the screw over the limits of one thread, or from *c* to *b*, it has actually been carried up the inclined plane from *a* to *b*.

Figure 53.

Figure 54.



157. The screw has no power by itself. It can operate only by means of pressure against the threads of another screw which overlaps it and holds it. This exterior screw, which is technically called a *box* or a *nut*, consists of a block with a

128. Explain the first diagram.
129. What does the second prove?
130. Explain the relation between the nut and screw.

central tube cut out in spiral grooves so as to fit with perfect exactness with the screw which has to work in it. Figure 54 represents both screws in combination. M is the box or nut through which the screw passes. L is a lever inserted into the head of the screw, for the purpose of turning it.

158. The object required by the use of the screw is to apply force or pressure. To produce the intended effect, either the outer or inner screw, that is, either the nut or the screw, must be fixed. If the screw be fixed at one extremity, say at the top, to a solid body, the nut may be turned round it so as to move from the bottom to the top; and if the nut be fixed, held fast by some solid body, the screw in the same manner may be turned round till it reach its extremity. Thus, either the point of the screw, or the nut, may be forced in such a way as to squeeze or press any object presented to them.

159. Practically, the screw is never used as a simple machine; the power being always applied by means of a lever, passing either through the head of the screw, or through the nut. The screw, therefore, acts with the combined power of the lever and inclined plane, and in investigating the effects, we must take into account both these simple mechanical powers, so that the screw now becomes really a compound machine.

160. In the inclined plane, as has been seen, the less it is inclined, the more easy is the ascent, though the slower is the process of rising to a certain elevation. In applying the same principle to the screw, it is obvious, that the greater the distance is betwixt the threads, the greater or more rapid is the inclination, and, consequently, the greater must be the power to turn it under a given weight. On the contrary, if the thread inclines downwards but slightly, it will describe a greater number of revolutions in a given space, so as to diminish the distance betwixt the threads, and the smaller will be the power required to turn the machine under a given weight. Therefore, the finer the screw, or the nearer the threads to each other, the less the power will require to be for a given resistance.

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131. Why is the screw called a compound machine?
132. How is the power of the screw regulated?

161. Suppose a case of two screws, one having the threads one inch apart, and the other half an inch apart; then, the force which the first screw will give with the same power at the lever, will be only half that given by the second. The second screw must be turned twice as many times round as the first, to go through the same space. At the lever of the first, two men would raise a weight to a given height, by making one revolution; while at the lever of the second, one man would raise the same weight to the same height, by making two revolutions.

162. It is apparent, that the length of the inclined plane up which a body moves in one revolution, is the circumference of the screw, and its height, the interval between the threads. The proportion of the power would therefore be—"as the circumference of the screw is to the distance between the threads, so is the weight to the power." By this rule, the power of the screw could alone be found, provided the action of the machine was not affected by the lever which works it. As that is the case, the circumference described by the outer end of the lever employed is taken instead of the circumference of the screw itself.

RULES FOR CALCULATING THE POWERS OF THE SCREW.

163. The rule by which the true force of the screw is calculated, is, by multiplying the circumference which the lever describes by the power. Thus—THE POWER MULTIPLIED BY THE CIRCUMFERENCE WHICH IT DESCRIBES, IS EQUAL TO THE WEIGHT OR RESISTANCE, MULTIPLIED BY THE DISTANCE BETWEEN THE TWO CONTIGUOUS THREADS. Hence the efficacy of the screw may be increased, by increasing the length of the lever by which it is turned, or by diminishing the distance between the threads. If, then, we know the length of the lever, the distance between the threads, and the weight to be raised, we can readily calculate the power; or, the power being given, and the distance of the threads and the length of the lever known, we can estimate the weight which the screw will raise.

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133. What illustration is stated?
134. How is the power calculated?

164. Suppose the length of the lever to be forty inches, the distance of the threads one inch, and the weight 8000; required—the power, at the end of the lever, to raise the weight. The lever being 40 inches, the diameter of the circle which the lever describes is double that, or 80 inches. Reckoning the circumference at thrice the diameter (though it is a little more), we multiply 80 by 3, which gives 240 inches for the circumference of the circle. The distance of the threads is one inch, and the weight 8000 pounds. To find the power, multiply the weight by the distance of the threads, and divide by the circumference of the circle.

8000 weight
1 distance

240)8000

$33\frac{1}{3}$

165. *Thirty-three and a third* is the product, and it would require that power or number of pounds to raise the weight. This, however, is only in theory. In practice, a third of the amount of power would require to be added to overcome the friction of the machine.

166. In the ordinary working of the screw, velocity is incompatible with great power. This is a truth, however, which applies only to a screw with one thread. There is a way of making a screw, by which great velocity and power may be combined. This is done by forming the screw with two, three, or more threads. To understand how this is accomplished, we have only to conceive the idea of a screw with one thread, very wide betwixt its turns, and then imagine one or two other threads placed so as to fill up the intervals; thus composing a fine close screw. And as by this means all the threads descend with equal rapidity, we have a screw which will not only descend with great velocity, but which will apply a very great degree of pressure. A screw of this nature is used in the printing press,

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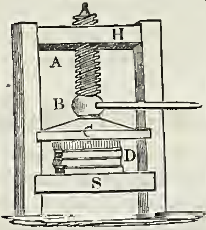
135. Repeat the example of calculation.
136. What of the friction of the machine?
137. How is velocity and power combined in a screw?
138. What remarkable instance is given?

by which a pressure of a ton weight is applied instantaneously by a single pull of a lever.

EXAMPLES OF SCREW POWERS.

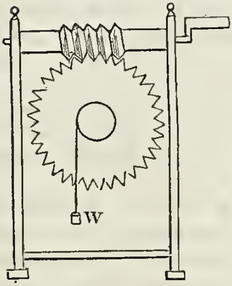
167. The most common purpose for which the screw is applied in mechanical operations, is to produce great pressure accompanied with constancy of action, or retention of the pressure; and this quality of constancy is always procurable from the great friction which takes place in the pressure of the threads on the nut, or on any substance, such as wood, through which the screw penetrates.

Figure 55.



168. The common standing-press used by bookbinders for pressing their books, affords one of the best examples of the application of the screw to produce great pressure. Figure 55. The screw A has a thick round lower extremity B, into holes in which the lever is inserted. This extremity B is attached by a socket joint to the pressing table C, so that when the screw is turned in one direction, the table sinks, and when turned in another, the table rises. The books D lie upon a fixed sole S, and are thus between the table and the sole. H is a cross beam above, in which is the box or overlapping screw to give the necessary resistance.

Figure 56.



169. The force of the screw is sometimes employed to turn a wheel by acting on its teeth, by which means there is a combination of two mechanical powers—the screw and the wheel and axle. Figure 56. The screw is upon

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139. What is the most common mechanical use of the screw ?
140. Explain the first diagram.
141. What combination produces the endless screw ?

the horizontal spindle, and by turning it by the handle, each turn of the thread receives a tooth of the wheel and brings it forward, so as to produce a perpetual revolution of the wheel. This is called an endless screw, because it never stops in its action; no sooner is one turn of the thread disengaged than another has come into operation. W represents a weight to be raised hanging from the circumference of the axle.

170. The screw concludes the list of simple mechanical powers, according to the usual definitions of science. But, to prevent misconception, it has to be noted that there are other means and agents of force in nature besides those comprehended in the number of simple mechanical powers working by solids. These will come under obseivation in the subsequent departments of NATURAL PHILOSOPHY.

MECHANICAL COMBINATION AND STRUCTURE.

171. Mechanical action, as already stated (3), is applied to the action of forces that produce no change in the constitution of bodies, and is therefore distinguished from chemical or any other species of action in which change of constitution is less or more effected.

172. Great changes are continually taking place in nature and art by mechanical action. Mechanical action generally implies movement or change of place, and in most cases alteration of external features and circumstances. The whole of the planetary movements are mechanical; the motions of water and winds are mechanical; and the new appearances produced in art by placing different objects together, are mechanical.

173. The action of forces upon solids, or mechanical action, is taken advantage of by mankind for the production of numerous useful results in the arts. And success in attaining these results depends in a great measure upon the knowledge we have of the principles of Mechanics, and the skill and care we use in applying them.

142. How does mechanical action differ from chemical?
143. Give instances of mechanical action.

174. When skill, care, and ingenuity, are brought fully into operation for these results, very great wonders are in many instances achieved. But where there is ignorance or negligence, the object in view may not only be defeated, but very mischievous consequences may take place.

175. Example first.—If a tall mast or beam break through at two-thirds of its height, and the two fractured ends be simply placed together and tied with a rope, the upper piece will, by the action of a small force, again fall. It will act like *the arm of power of a lever* against the rope, which is the *weight;* and as this weight is inconsiderable, the arm of power will preponderate. But if we take the two pieces and saw each of them lengthwise, so as to make four pieces, and then, as represented in figure 57, lay a short piece alongside of a long piece, and another long piece on the top of the first short piece, with the second short piece opposite to this second long piece, the whole will be effectually *spliced* together; in such a case, with the aid of an overlapping rope, the beam will in all likelihood be stronger than it was before it was fractured. The cause of its being stronger, at least of its remaining firm, is, that the weaker part at one side is supported by a stronger part on the other side. Thus, by skilfully taking advantage of certain forces acting in connexion with solids, we are able to rear a structure of the utmost possible strength.

Fig. 57.

176. Example second.—If a man, in making repairs upon the outside of a building, project a plank from a window for the purpose of standing upon it, and if he proceed to place himself near the outer extremity of the plank, without having placed a sufficient counterbalancing weight at its inner extremity, he will assuredly be precipitated to the ground, and perhaps killed; because the *gravity* of his body acted like a *power* on the arm of a lever, while the lever was without a sufficient *weight* to preserve the appa-

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144. How are the principles of mechanics important in the arts?
145. Explain the example and diagram.
146. What is the second example?

ratus in equilibrium. From such neglects of the operation of forces in nature, dreadful consequences frequently ensue.

177. The study of the operation of mechanical forces, along with experience, teaches that there are certain bulks, positions, and forms of bodies, which produce the greatest strength for purposes of art.

178. The strength of beams or masses of the same kind and bulk, and fixed in the same manner, in resisting a transverse force which tends to break them, is simply as their breadth, as the square of their depth, and inversely as their length—that is the thicker and shorter they are, they are the stronger. Thus, if a beam be twice as broad as another, it will also be twice as strong; for the increase of breadth doubles the number of the resisting particles. By making the beam double the depth, the strength is four times as great; because the number of fibres is doubled, and the lever by which they act is also increased.

179. But this increase of strength, by increasing bulk, has a practical limit. It is found that increasing the dimensions of a body, or combination of bodies, preserving all proportions the same, *the weight increases more rapidly than the increase of strength, or power of endurance.* This is one of the most important principles in mechanical science, and ought to prevent undue extension in structural arrangements. (39.)

180. Take a block of stone, and fix one end of it into a wall, leaving its other end projecting. By this arrangement of position, each particle of matter in the block acts as a weight pulling downwards as with a lever, the fulcrum of the lever being at the point of support, and the particles of matter in the mass forming at once the arm of power and the weight. Hence every particle we add to the length of the block, adds to the length of the arm of the lever, and increases the weight. If we add to the block beyond a certain length (whatever may be its constitutional strength), we shall certainly cause the mass to break, and fall, from the effect of gravity, upon the outer extremity.

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147. How is the strength of beams estimated?
148. What of undue extension?
149. Cite the examples here given.

181. A similar lever action takes effect in the case of blocks or beams supported at both ends, the only difference being, that, in extending them to an undue length, they will break in the middle, or at the weakest point between the two supports.

182. The strength of a beam supported at both ends is twice as great as that of a beam of half the length, which is fixed only at one end; and the strength of the whole beam is again increased, if both ends or fulcra be firmly fixed, as into a wall.

183. In the case of fibrous or grained materials, as for instance, wood, the body sustains the greatest pressure when the weight is applied to the grain endwise, or to the beam longitudinally. The nearer that the pressure can be applied to any beam endwise, the better. Thus a beam supports most weight on its upper end, the other end being fixed to the ground, and its strength is next greatest when the pressure is applied to it leaning at top against another beam. This is exemplified in the angular roof of houses, in which two beams lean against each other like the two sides of the letter A. In arranging beams to support great weights, as in building bridges, each beam is made to push obliquely upward with one end, while it pushes obliquely downward with the other, and thus an extensive combination of beams is firmly supported.

184. In rearing structures consisting of beams, it is an important point to convert, as far as possible, by mode of erection, cross or transverse strains into longitudinal strains or into forces acting on the ends of beams, in the direction of their length.

185. Nature appears to have designed that strength of structure should be accomplished with the least expenditure of material. It is obvious, that, if trees and animals were made many times larger than we now find them, and of the same kinds of substance, they would be borne down by their own weight. Small animals endure greater comparative violence, and perform greater feats of strength, in pro-

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150. What rules are given in using fibrous materials?
151. What is said of trees and animals?

portion to their size, than large ones. The largest bulk which a human being can possess in his person, at the same time retaining activity of motion, is not more than is usually seen in well-grown men. Thus, from a simple natural cause, men of very gigantic figure never could have existed on our earth. Men must always have been about the size which they are at present; or, if they were considerably larger, they must have been constituted of much stronger materials, without a corresponding increase of weight.

186. The same principles relative to mechanical strength apply to contrivances in the arts. As already stated, the strength or power of endurance in a material does not increase in proportion as the weight increases. Hence there is a practical limitation of the magnitude of machines and other structures. For example, a bridge or roof of beams may be very strong when of small or moderate size, but if the dimensions be extended beyond a certain limit, the structure will fall by not being able to support its own weight.

187. The strength or power of endurance of pressure upon a fixed body, is greatly increased by giving the body a certain form. The strongest form in nature or art is that of an *arch.*

ARCHED STRUCTURES.

188. An arch is a skilful disposition of parts, forming a convex and concave side, the convex side being that upon which the pressure is applied. The arch, which takes its name from *arcus*, a Latin word signifying a *bow*, may be either a portion of a circle or ellipse, or entirely rounded in form. Whether shaped like a bridge, a round tube, or the shell of an egg, the principle which causes the power of endurance of pressure is the same.

189. The principle of endurance consists in the particles of the arched body bearing upon each other like a series of

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152. Why is it certain that giant stories are fabulous?
153. What of the proportion between material and strength?
154. Which is the strongest form in nature or art?
155. Define an arch, with examples of their variety.

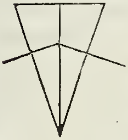
wedges, thus causing a compression of particles on the concave side of the circle, which enables the mass to bear an enormous pressure on the convex side. Indeed, the greater the pressure is (to a certain extent), perpendicular to the convexity, so also the compression and power of resistance become the greater.

190. In the case of arched objects which have to meet resistance on all sides, the circular form is best. In the case of objects such as arches of bridges, which are exposed to pressure chiefly on one side, the semicircular form is the strongest, or offers the greatest resistance. The more that the figure of an arch departs from the true circle or semicircle, the weaker it becomes.

191. In arched forms such as tubes or egg-shells, the compression of particles takes place all round the inside of the object, so that the arch presents a power of resistance at any part of its convexity; the power being always greatest where the convexity is greatest. For example, it is more difficult to break an egg by pressing against the two ends than against the sides.

192. In the representation of a regular-sided wedge, figure 58, to which the side pressures are applied at right angles to the sides, it is seen that the lines of direction of the two forces or pressures proceed obliquely to a point within the wedge. The same principle applies to the particles or blocks composing arches—the pressing forces meet in a point within the particles or blocks, and the situation of this point is governed by the degree of convexity of the arch, that is, the degree of inclination of the respective wedges.

Figure 58.



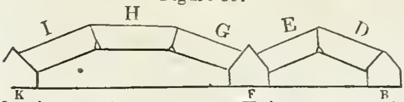
193. Hollow cylindrical tubes, shafts, pillars, or other objects of art, are much stronger than the same objects would be if solid, with the same quantity of material. Plates of metal bent into grooves on the surface, are similarly much stronger than the same plates when flat. This

156. Explain the principle of its strength.
157. How illustrated by an egg.
158. Explain the diagram.

is well exemplified in the roofing of the large warehouses and wharfs at the London Docks, which are covered with sheets of iron. The sheets are thin in substance, but bent into semicircular grooves and ridges, and have all the strength of thick plates without their dangerous weight.

194. In arched forms such as bridges, in which there is only part of a circle or ellipse, the two extremities of the arch must rest against immoveable piers or abutments, sufficiently strong to resist the horizontal thrust upon them; for it is upon these parts of the structure that the pressure takes effect.

Figure 59.



195. Figure 59 represents the simple elements of two arches. B is an outer pier, fixed firmly on the ground. F is another pier, and betwixt the two there are two wedge-shaped stones, E and D, lying obliquely to each other. It is obvious that the more these two stones press downwards, they will more firmly sustain each other. The pier F serves as a prop to the other arch, which consists of G H I, and is supported at the other extremity by the fixed pier K. The three stones in this arch press against each other in the same manner as in that with the two stones; and the same principle operates, although the arch consists of fifty or a hundred stones. The central stone of all arches is the stone which binds the mass together, as in the case of H, in the figure, and is technically called the *key-stone*. It is always the last inserted.

196. A similar action of mutual pressure to preserve equilibrium, occurs in all arched forms. The human foot is an arch consisting of small bones bearing on each other, at once to give strength, lightness, and elasticity.

197. Anciently, bridges were built of a purely semicircular form, giving a considerable convexity or rise in the

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159. What example of grooved material is given?
160. Where is the pressure in arched bridges?
161. Explain the diagram.
162. What of the human foot?

middle. This was an inconvenient form for a bridge. Architects now make bridges with elliptical or slightly curved arches, so that the passage above them is, in most cases, as easy as along a piece of ordinary road. Although these modern slightly curved arches are not strictly so strong as a perfect semicircular arch, they are sufficiently durable for all necessary purposes.*

ELEMENTS OF PRACTICAL MACHINERY.

198. The term *machine* is ordinarily applied to any piece of mechanism, or engine, in which different parts are combined to produce the desired effect. In NATURAL PHILOSOPHY, a machine of this composite nature is called a *complex machine* (4).

199. The treatment of the principles on which complex machines operate, forms the subject of the department of NATURAL OR MECHANICAL PHILOSOPHY termed PRACTICAL MACHINERY.

These principles are now to be defined.

200. The simple mechanical powers compose the elements of all machines, however complex or extensive. Thus, in all machines, levers, cords, or inclined planes, in their different modifications, are found to be the elementary component parts of the structure, and all combined in harmonious union to accomplish certain results.

201. Machines are usually formed of wood, iron, steel, brass, or other durable materials, with sometimes leather and cordage as part of the apparatus.

202. In the construction of every machine, four objects are particularly desirable—1st, Strength or durability of materials; 2d, Simplicity of arrangement of parts; 3d, Exactness of fitting of one part to another; and 4th, Easiness

* A further consideration of the subject of strength of materials belongs to PRACTICAL MATHEMATICS.

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163. What improvement is there in modern bridges ?
164. Define a complex machine.
165. What powers are combined in their structure ?
166. What four objects are sought in machines ?

and correctness of motion. It is a general and well-recognized principle in mechanics, that the *fewer the parts* are in a machine, and the *more simple its construction*, the better.

203. Machines act from the impression of a certain power or force communicated to them. Whatever be the amount of power they receive, that amount they expend in their action. They cannot in the smallest degree increase the power. They can only convey, regulate and distribute, the quantity of power which has been communicated to them.

204. The power communicated to machines is derived from various sources; as, human labour, the power of horses or other animals, the force of wind, water, or steam, or any other active agent, which may be found suitable. Sources of power are technically called *moving forces* or *first movers.*

205. Of the original imprèssed power, each moving part of the machine uses a certain portion. If the whole power which enters a machine be supposed to consist of 1000 parts, this large quantity is dispersed in various small quantities through the mechanism; some wheels taking perhaps 10 parts, others 5 parts, a third kind 1 part, a fourth a fractional part, friction another part, and so on, till the whole 1000 parts are expended. In some large cotton, flax, or silk spinning establishments, a single water-wheel or steam-engine turns several thousands of spindles; each spindle, consequently, consumes a minute fraction of the originally impressed power.

206. Whatever be the nature of the moving forces, it is generally sufficient for all purposes that they produce in the first instance *rotary* or *circular motion*, and either in a horizontal or vertical direction. It is, however, indispensable that the power be of that magnitude which will cause each part of the machine to fulfil its assigned office. If the power be too small or weak, the machine will move languidly and ineffectually; and if too great, it will either cause the ma-

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167. What moving forces are employed ?
168. How is the power divided ?
169. What illustration is cited ?
170. What motion is desirable ?

chine to move too rapidly, or at least power will be expended uselessly. In the application of moving forces, it is always a matter of importance to regulate the power to the precise wants of the machinery.

207. The circular motion communicated in the first instance to a machine, is, by means of certain contrivances, diffused through the whole organization, and changed into every conceivable direction; some parts being caused to revolve, others to rise and fall, a third kind to move horizontally to and fro, and so forth, in all possible ways. The various parts may also be made to move with any degree of velocity; there being methods of transforming quick into slow motion, or slow motion into quick. Most minute and complex operations are thus performed by machines with a precision which often exceeds the skill of the most expert artizan, but these operations are all necessarily marked by the quality of *uniformity of action.* As machines cannot reason, or act arbitrarily in stopping, moving, or altering their process, according to circumstances, they proceed in a blind routine, whether right or wrong, *mechanically* as it is called, and in every case less or more require the superintendence of reasoning beings. This apparent defect, however, is really advantageous. A machine by being composed of inanimate matter, destitute of feeling and unsusceptible of fatigue, proceeds unswervingly in its assigned duty, and may be forced to accomplish tasks which it would be both inhuman and impolitic to demand from living creatures.

208. The purpose of machinery, therefore, is to *lessen and aid human labour.* At an inconsiderable expense, and with a small degree of trouble in supervision, a machine may be made to do the work of ten, fifty, or perhaps as many as five hundred men; and the work so simply effected by inanimate mechanism, serves to cheapen and extend the comforts and luxuries of life to the great body of the people.

The following are the chief elementary parts of machinery:—

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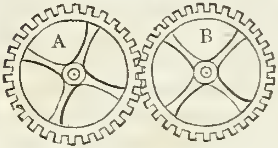
171. What of conformity of action and how obtained?
172. What is the great purpose of machinery?

WHEELS.

209. A wheel moving on a central axis is a lever with equal arms radiating from the fulcrum at the centre, and is thus called a perpetual lever.

210. Wheels may be used in machines simply to transmit power from one point to another. This is done by means of toothed wheels. Projecting teeth or *cogs* are placed all round the circumference of a wheel, and, when the wheel is turned, these teeth work upon or press against the teeth of another wheel, and so cause it to turn also, but in an opposite direction. Figure 60 represents two wheels so working upon each other. As both of these wheels are of the same size, and consequently are levers with equal arms, they do not alter the effect of the power communicated to them. The motion of the axle in the wheel B is the same as the motion of the first axle in the wheel A. Thus, power may be *transmitted* from one point to another.

Figure 60.



211. A long and large axle, in wheel-work, is called a *shaft*, and shafts of small dimensions are termed *spindles.* The terminating points of axles, shafts, and spindles, where they rest and turn upon supports, are called their *pivots* or *gudgeons.* The *sockets* upon which the gudgeons bear in turning, are sometimes termed *bushes.*

Figure 61.

WHEELS AND PINIONS.

212. When power has to be *accumulated* or increased in its effect in the course of its transmission, a large wheel is made to play upon a small wheel, by which means there is

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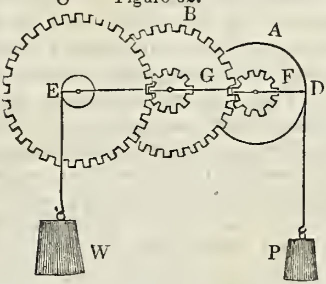
173. How do we obtain a perpetual lever ?
174. How is power transmitted ?
175. Explain the first diagram, and the italicised terms.
176. How is power accumulated ?

a diversity in the lengths of the levers. Figure 61 is a representation of a large wheel W, working on a small wheel or pinion P The wheel is turned by the handle C. In all arrangements in which large wheels are moved by small wheels, or small wheels by large, the small wheels are called *pinions;* and when these pinions are broad in their dimensions, they are termed *trundles.*

213. In this combination of a wheel and pinion, a long perpetual lever works against a short perpetual lever, by which a considerable mechanical advantage is gained. The wheel may be supposed to possess 48 teeth and the pinion 6 teeth; hence by one revolution of the wheel, the pinion turns 8 times, which gives the axle of the pinion eight times the velocity of the axle of the wheel; and if we suppose that the diameter of the wheel is ten times the diameter of the pinion, the power is increased in effect ten times.

214. Any degree of velocity greater than that of the first rotary motion, may be imparted to the parts of a machine, by making these parts so much smaller than the primary moving parts. Thus, if a large wheel, having a thousand teeth in its circumference, work upon and turn a small wheel having only ten teeth in its circumference, the small wheel will go round one time for every ten teeth of the large wheel which it touches; or, in other words, it will go round one hundred times for one time of the large wheel.

Figure 62.



The respective velocities of wheels in a machine are, in this manner, always proportionate to their diameters, or size, unless when specially arranged to be otherwise.

215. A combination of wheels acting as perpetual levers, is represented in figure 62. Three wheels are placed in a

177. What example is given?
178. How is velocity indefinitely increased?
179. Explain the diagram and its principles.

row close to each other, and it is supposed they are fixed by three axles to some upright object. On the side of the first wheel A, there is attached a small toothed pinion or wheel F, which, by the pressure of its teeth on the teeth of the second wheel B, causes this second wheel to turn round. The power applied to produce this motion is at the circumference of the first wheel at D. From D then, to the centre of the pinion E, is the long arm of a lever, of which the centre of the pinion is the fulcrum; and from the centre to the ends of the teeth of the pinion is the short arm. The second wheel B having received its motion, the toothed pinion G, which is similarly attached to its side, presses against the teeth of the third wheel C, and so causes it also to turn. In this way a second lever is put in action. And the third wheel, from its circumference to the point from which the weight W depends, is a third lever. As the power or small weight P falls, therefore, from the circumference of the first wheel, the resistance W is raised, with the accumulated force of three levers acting on each other. The line across the figure represents the three levers in action.

216. To calculate the power or mechanical advantage to be gained by such a machine, suppose the number of teeth on the first wheel to be six times less than the number of those on the circumference of the second wheel, then the second wheel would turn round only once, while the first wheel turned six times. And, in like manner, if the number of teeth on the circumference of the third wheel be six times greater than those on the axle of the second wheel, then the third wheel would turn once, while the second wheel turned six times. Thus, the first wheel will make 36 revolutions, while the third wheel makes only one. The diameter of the first wheel being three times the diameter of the axle of the third wheel, and its velocity of motion being 36 to 1, three times 36 will give the weight which a power of 1 pound at P will raise at W. Three times 36 being 108, one pound at P will balance 108 pounds at W.*

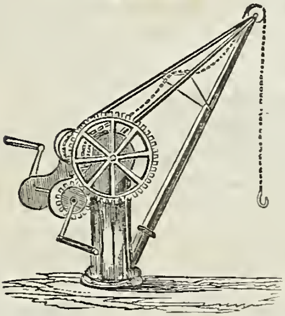
* In some works, the product of the force multiplied by the arm of the lever with which it acts, is technically called its *moment*—as "the moment of the power," "the moment of the weight."

179. How is its power calculated?

PRACTICAL EXAMPLES.

217. Figure 63 is a representation of a machine called a crane, which is in very common use for lifting heavy weights. This machine affords a good practical example of a combination of wheels or perpetual levers, acting so as to *transmit* and *accumulate* power. Two levers operate in the machine; the first arm is from the handle to the axle of the first or small wheel; the second arm is this first wheel from its axle to its toothed circumference; the third arm is the second or large wheel from its toothed circumference to the centre of its axle, and the fourth arm is the radius of the axle. By turning the handle, the first wheel is turned, which gives motion to the large wheel, which causes the axle of the large wheel to warp up the chain which is seen proceeding from it. Thus, any heavy weight attached to the hook at the outer extremity of the chain is lifted. Here, then, the advantage of two lever powers is brought into operation, or concentrated upon the weight attached to the hook. The machine possesses two handles working on one axle, so that two men, if necessary, may work at it. But there is a way of adding power without using two handles. This consists in giving the machine another wheel. This additional wheel is placed between the small and large wheel, so as to afford another lever power. In this manner, we may go on adding wheels, till at length the touch of a finger is sufficient to raise a ton weight. But, as already often mentioned, this advantage is procured only by a loss of time or speed. In usual cir-

Figure 63.



180. Explain the diagram.
181. What precaution is necessary in toothed wheels ?

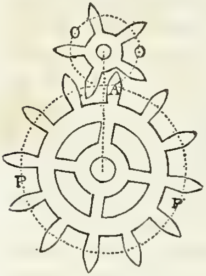
cumstances, the labour of one or two men is employed, which gives sufficient speed in the operation.

218. The crane, as we have represented it, is strongly, but elegantly, constructed of iron. Standing on the ground upon a pivot, it may be turned about to any side, so as to bring the hook over a cart, or over a vessel from a wharf, with the smallest trouble. This conveniency in construction causes it to be extensively used in shipping operations at wharfs.

WORKING OF TOOTHED WHEELS.

219. In the working of toothed wheels one upon another, or of wheels working on pinions, it is essential to set them in opposition with such exact adjustment, that the teeth of one will fall into the hollows betwixt the teeth of the other. When the teeth of each do not work with this nicety, they are apt to jar upon and break each other, and so damage the machine. In some cases teeth are made of a round or pointed form at their extremities, by which a very small degree of grinding or pressing on each other takes place. Figure 64 is an example of a wheel and pinion with rounded and pointed teeth. From the centre of the axis of the pinion L to the centre of the wheel C, a dotted line is marked, called by mechanics the *line of centres.* The dotted circle O O round the pinion, and the dotted circle P P round the wheel, indicate the true point of working or contact of the teeth upon each other. These two circles are seen to join with exactness at A.

Figure 64.



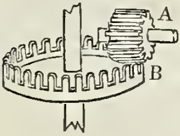
ALTERING THE DIRECTION OF MOTION.

220. Motion often requires to be *altered in its direction* in the course of its transmission. For example, rotary

182. Explain the diagram.
183. What of altering the direction of motion?

horizontal motion requires to impart rotary vertical motion, or rotary vertical motion to impart horizontal motion. By means of a peculiar mode of setting the wheels, and a corresponding peculiarity in the shape of their teeth, any alteration may be effected in the direction of the motion.

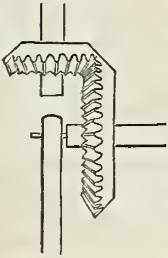
Figure 65.



221. Figure 65 represents a plan of changing the direction of motion. A is a pinion or trundle working with its shaft horizontally on a wheel B, whose shaft is turning vertically. As the case may happen to be, the horizontal movement is causing the vertical movement, or the vertical movement is causing the horizontal movement.

BEVEL WHEELS.

Figure 66.



222. Figure 66 represents a more common plan of changing the direction of motion. The wheels in this case are bevelled. A *bevel* wheel is a wheel with teeth placed in a sloping or oblique direction on its circumference. When two bevel wheels are placed at right angles with each other, their respective teeth work against each other, and so a harmonions joint motion ensues. This is exemplified in the figure, in which a horizontal shaft with a bevel wheel, is seen turning a smaller bevel wheel above it, placed on a vertical shaft.

TRANSMISSON OF POWER BY BELTS.

223. A common plan of transmitting power from one point to another, when the interval is considerable, is by a flat leather band, strap, or belt, communicating from a wheel at the source of power to a wheel connected with the machine.

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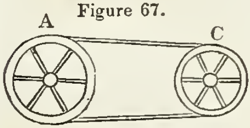
185. Explain the first diagram.
186. What of bevel wheels?
187. What other mode of transmitting power?

224. The wheels upon which straps work are usually called *pulleys.* They have flat and broad rims, and these rims have sometimes narrow ledges, to prevent the belt from slipping off. The rims must also be rather rough on their surface, so as to give the belt a sufficient friction or power of pulling in performing its revolutions.

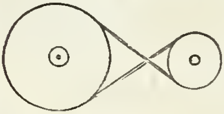
225. Figure 67 represents the transmission of power by a belt. A is the first pulley, which has received the power from its source, and C is the second pulley, moved by a belt, which passes over both pulleys. In this case the motion of A is transmitted by the belt to C, which it causes to turn in the same direction as A. If these two pulleys were of precisely the same diameter, and the belt did not relax or slip, the second pulley would unavoidably go at the same velocity as the first, because the belt has exactly the property of a toothed wheel, and simply transmits the power it has acquired. As C appears to be somewhat smaller than A, it would consequently turn more frequently than A; therefore, we have here an example of the mode of increasing the velocity while transmitting power.

Figure 67.



226. Figure 68 is a representation of two pulleys moving in different directions by means of a belt. The large pulley is supposed to be that which has received its power from its source. The belt after leaving it, is crossed, and, therefore, it causes the small pulley to move round in a direction opposite from that of the first. Here, also, the second pulley is smaller than the first, and therefore moves with an increased rotary velocity.

Figure 68.



227. Crossing the belt serves two purposes. It changes the direction of the rotary motion which is sometimes required in machinery, and causes the belt to move more steadily. When the belt is long, it is apt to vibrate consid-

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188. Explain the first diagram.
189. Explain the last diagram.

erably in its motion, from its weight being unsupported at the centre.

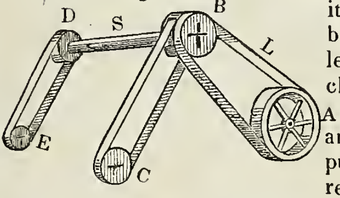
228. Power might be transmitted to any distance by belts without loss, if their weight, vibratory motion, and tendency to slacken, did not present obstacles to transmission to any considerable distance. Practically, belts are not generally employed to transmit power to above a distance of twenty or thirty feet, and more frequently the distance is from ten to fifteen feet.

SHAFTS AND PULLEYS.

229. When power requires to be carried to a distance beyond that which belts can conveniently manage, the transmission is effected by a long shaft; and if it be necessary to change and rechange the direction of the motion, bevel wheels are added. Or the transmission may take place by a long flat chain acting like a belt, but caused to travel over small wheels or pulleys, to prevent the chain hanging down in any part of its course. A chain of this nature is called an *endless chain.*

230. Motion is often required to be communicated to many different machines, *at different points*, from one source of power. This is effected by means of a shaft and pulleys. From the pulley which receives the first motion, a belt is sent to a pulley fixed upon a shaft, which shaft is generally hung horizontally from the roof over the machines. As the shaft turns through its whole extent, it is able to turn pulleys fixed at any point upon it, and from these pulleys, belts are sent down to pulleys at the respective machines.

Figure 69.



231. Figure 69 represents an apparatus of a sha t and pulleys. A is the pulley receiving motion from the

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190. What are the disadvantages of belts ?
191. How are shafts and pulleys used and why ?
192. Explain the first diagram.

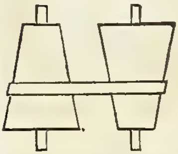
source of power, and, by means of the belt L, turns the pulley on the end of the shaft S. At the same time the pulley D at the opposite end of the shaft is turned. From a pulley on the shaft situated close to B, a belt descends to turn C, and from D another belt descends to turn E. Thus, an extended axle or shaft from C will turn a machine, and an extended axle or shaft from E will turn another machine. The apparatus can turn two machines.

232. Shafts with pulleys, working on the plan now stated, are to be seen at almost every considerable manufactory in which machinery is employed; and the power, by means of bevel wheels, and upright connecting shafts, is carried upwards from story to story in a building, giving motion to hundreds of wheels, spindles and other parts of the mechanism.

CHANGING VELOCITY.

233. It is sometimes necessary that a machine, or part of a machine, should be propelled with a velocity which is not equable, and is continually changing from fast to slow and slow to fast. This happens in cotton mills, where it is necessary that the speed of certain parts of the machinery should continually decrease from the beginning to the end of an operation. To effect this an apparatus is used, as represented in figure 70. Two cones, or conically shaped drums, are used, having their larger diameters in contrary directions. They are connected by a belt, which is so governed by proper mechanism, that it is gradually shifted along from one extremity of the cones to the other, thus acting upon circles of different diameter, causing a continual change of velocity in the driven cone with relation to that which drives it. The shifting of bands from large to small wheels, and from small to large, has similar effects.

Figure 70.

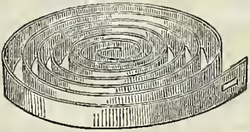


193. What examples of their use are stated?
194. How is velocity changed?

PRESERVING REGULARITY OF MOTION BY A VARIABLE FORCE.

234. In some mechanical contrivances, the force which is applied varies in its intensity, while the wheels of the machinery require to be kept at a uniform speed. This is generally the case when the force is communicated from a steel spring, which, after being wound up, is suffered to relax. Figure 71 is a spring suited for operations of this kind. It is represented in a state of relaxation, and is wound up into a compact form by means of a spindle fixed to its inner extremity. The coiling of a strip of paper round the finger, and allowing it to unwind itself, is a familiar illustration of the action of a spring of this description.

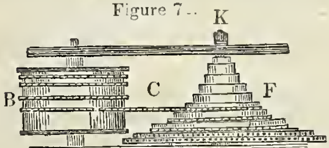
Figure 71.



235. The force communicated by the relaxing of the spring varies in its intensity. The force is greatest when it begins to relax, and it gradually weakens till its expansive energy is exhausted. To compensate this defect, a very ingenious plan is adopted, and which is put in operation in the apparatus of the common watch.

236. Figure 72 represents the apparatus of motion of a watch, somewhat magnified. The spring is confined in a brass cylinder or barrel B. To this barrel the spring is attached by a slit at its outer extremity. The inner extremity of the spring is fixed by a similar slit to the central axis or spindle. F is a brass cone, broad at bottom and narrow at top, with a path winding spirally round it as an inclined plane. This cone is called the *fusee*, and has also a central axis or spindle K, to which it is fixed. To a point on the lower inclined path of the fusee, a small steel chain C is attached, and the other extremity of this chain

Figure 72.



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195. Explain the first diagram and how uniform velocity is secured.

is attached to the top part of the barrel. When the spring is relaxed, the chain is almost altogether round the barrel. To set the apparatus in motion, the watch-key is made to turn the spindle K, by which the chain is drawn from the barrel to the fusee, filling up the inclined path to the summit. The chain in leaving the barrel causes it to turn, and consequently to wind up the spring inside. The process of unwinding or relaxing ensues, and now the ingenious plan for regulating the motion is to be remarked. At first, when the force of the spring is greatest, the chain acts upon a small round of the fusee; in other words, it pulls with a small lever—for as already explained under the head WHEEL AND AXLE, a wheel or round object on an axis is simply a perpetual lever. In proportion as the intensity of the force weakens, and the barrel takes off the chain from the fusee, and winds it about itself, so does the chain act upon a longer lever, or so does it gain a greater lever advantage, by drawing at a wider part of the cone. Thus, the gradual loss of force is counterbalanced by a gradual increase of lever advantage. (The case resembles that of a strong man working with a short lever, and a weak man working with a long lever; both are equal in effect in balancing any resistance.) The wheelwork of the watch is moved by teeth on the lower circumference of the cone.

ALTERNATE OR RECIPROCATING MOTION—ECCENTRIC WHEELS.

237. Alternate or reciprocating motion is applied to movements which take place continually backwards and forwards in the same path. In most complex machines, both rotary and reciprocating motion occur, and these motions may be converted into each other by various contrivances.

238. A common contrivance for gradually raising and depressing an object by machinery, is that of an eccentric wheel.

239. An eccentric wheel is a wheel with an axis not in its centre, but at a point nearer one side than the other.

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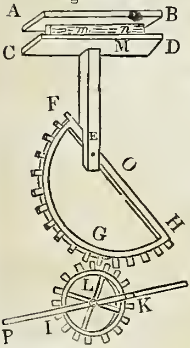
196. Explain the mechanism of a watch.
197. How is alternate motion secured?

Figure 73.

Figure 73 represents the action of a wheel of this kind. W is the wheel, and A the axis upon which it is fixed. When the axis turns, the wheel turns with it. As the axis never moves out of its place, the wheel necessarily describes a path of gradual rising and falling in its revolutions. Suppose an object, as T, pressing upon the upper edge of the wheel, so as to accommodate itself to the motion, it is obvious that, by the action of the wheel, this object will be alternately raised and allowed to fall. Or suppose that a rod is hung from a point of the wheel near where T rests, it is similarly obvious that the rod would be raised or depressed, according as the wheel turned. Thus, a rising and falling motion may be effected by an eccentric wheel.

240. Eccentric wheels are made of different forms. According as they may be required to act, they are circular, oval, heart-shaped, or pointed at one end, and so forth—the object in each case being to produce alternate motion, by continually altering the distance of some moveable part of the machine, from the axis about which they revolve. Technically, the projecting parts of eccentric wheels are called *cambs.*

Figure 74.



241. In some cases, eccentric wheels are not required to perform entire revolutions on their axes. It is perhaps sufficient for the purpose of the mechanism, if they gradually rise to the height of their power, and then, without turning round, gradually descend by retracing their course. An example of this kind of motion is given in the adjoining figure. L is a lower circular wheel turning on a fixed central axle, which axle rests on two supports not drawn in the figure. P is a bar or lever by which the axle is turned. By depressing the lever at P, the wheel turns,

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198. Explain the diagram.
199. Name the variety of eccentric wheels.
200. Explain the diagram.

and by its teeth propels the semicircular eccentric wheel above it. The eccentric wheel in going forward is compelled to rise to its full height, which height it has attained when its extremity at F is brought straight above E. In thus ascending, it pushes upwards the beam E, which is attached to it by an axle through E. The beam E consequently pushes up the board M, and presses any material, *m n*, against the topmost board A B. This topmost board is fixed to supports, not drawn in the figure, and neither rises nor falls. By this process of winding up the semicircular eccentric wheel, the utmost height of pressure of the machine is attained. The lever is then turned by a reverse motion, and the semicircular eccentric wheel comes to its lowest depression when its extremity at F is brought near to L.

242. The principle upon which this machine gives pressure, is that of the lever. In working the lower circular wheel against the eccentric above, there is a combination of two levers; and the power increases as the eccentric ascends, because the leverage of the eccentric is at every tooth increased in its length.

243. The leverage power given by an eccentric wheel or camb is one of the most convenient and ingenious applications of force. It is now used in small presses for stamping books and other processes in which a firm rapid pressure requires to be given. The example in figure 74 is that of a machine for pressing putty or any other soft material into moulds, to produce casts of ornaments; and it appears to be excellently adapted for the purpose.

244. When an alternate rising and falling is required *twice* in a piece of machinery, by only *one* revolution of an axle, an eccentric wheel is used of an oval form, with the axle in the middle of the oval, by which means each end of the oval rises in the course of a revolution.

245. When an alternate rising and falling is required *thrice*, by only *one* revolution of an axle, an eccentric wheel is used having three projecting cambs on its circumference, and as each camb comes round, it lifts and lets fall any

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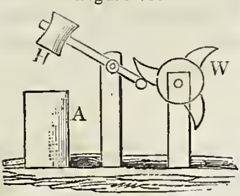
201. Upon what principle is this machine ?

object presented to it. An example of this apparatus is given in Figure 75. The object required is to work a heavy hammer upon an anvil for beating iron. W is the wheel with the three cambs, and it turns by an axle in upright supports. In turning, each camb, with its rounded or convex side, presses down the end of the handle of the hammer, so as to raise the heavy head H at the opposite end. After pressing down the handle and escaping, the head of the hammer falls with a heavy blow on the anvil A. There it remains till raised up and let fall by the next camb, and so on.

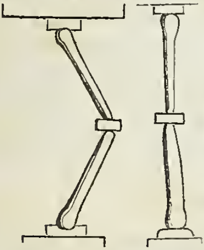
Figure 75.



OBLIQUE ACTION.

246. A mechanical advantage, which is frequently of a very serviceable nature, is obtained by causing the points of two straight bars to meet each other, but fixed loosely, so as to be free to move from an oblique to a straight direction, and the reverse. The power consists in bringing the bars to the straight, by which they force asunder or press hard upon any object presented to their outer extremities. In the adjoining figure, the bars are seen first in their oblique position, and next when brought towards a straight. Betwixt the two points a small hollowed piece of metal is inserted, in which the points work, and against which the power is exerted to produce the action. The straightening and bending of the apparatus resembles the action of the knee-joint in animals. The pressure produced by the forcing downwards of the outer extremity of the lower bar (the upper working against a fixed beam) is

Figure 76.



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202. Explain the diagram and its object.
203. What of oblique action and the example.

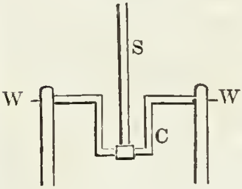
very easily and rapidly accomplished, and is almost unlimited; and these advantages, as well as the extreme simplicity of the mechanism, have led to the application of the power to the printing-press wrought by the hand, instead of screw pressure.

CRANKS.

247. The crank affords one of the simplest and most useful methods of changing an alternate rising and falling motion into rotary motion.

248. A crank resembles a common handle or winch for turning a machine by the hand; the chief difference being, that a rod or shaft jointed to the handle, and going up and down, works the machine. If the crank be made double, it will turn two wheels or machines.

Figure 77.



249. Figure 77 represents a double crank in action. S is the rod or shaft ascending and descending, and attached by a joint to the lower part of the crank C, which it alternately pulls up and pushes down, so as to cause the axles W W to turn a wheel at each side. Take away one of the sides of the crank and its support, and the apparatus becomes a single crank.

250. Turning-lathes, knife-grinders' machines, and similar apparatus, are usually turned by cranks wrought by an alternate pressing and raising of the foot of the operator; a rod going upwards from the foot-board to the crank, causing the wheel or spindle to go round. The crank has been hitherto indispensable in the action of the steam engine.

RATCHET WHEELS.

251. It is sometimes necessary to prevent wheels and axles, bearing the strain of heavy weights, from flying in a backward motion after being wound up. This purpose is

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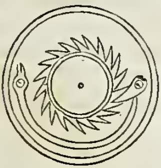
204. Define a crank and explain the diagram.
205. Cite examples of its use.

effected by fixing a ratchet wheel to the extremity of the axle. This wheel has teeth all round its periphery, inclining in one direction, and a small catch is so placed as to enter the indentations and stop the wheel if it inclines to turn backwards, but the catch slides over the teeth without obstructing them, if it moves forward. A spring pressing on the catch causes it to keep in its proper place. Figure 78.

Figure 78.



ENGAGING AND DISENGAGING MACHINERY.

252. In many cases, particularly where numerous machines are propelled by a common power, it is important to possess the means of stopping any one of them at pleasure, and of restoring its motion, without interfering with the rest. To produce this effect, various plans are pursued. The most common and simplest device, used in cases of motion by belts, consists in having a *live* and *dead pulley*. Alongside of the pulley whose axle moves the machinery, and on which the belt works, there is a pulley or wheel loose on its axle, called the dead pulley, from its inoperative character. When the machine is to be stopped, the belt is shifted from the live or active pulley to this dead pulley, which it turns without producing any effect on the machinery. Motion is restored to the machine by shifting the belt back to the live pulley. A long rod with a clutch at its extremity, and easily affected by the hand of the workman, turns the belt off or on at a moment's notice.

PRACTICAL MACHINERY CONTINUED—OF ACCUMULATING AND EQUALISING POWER.

ACCUMULATION.

253. Power is susceptible of accumulation—that is, of increasing little by little—and of being expended either

206. What are ratchet wheels and their use.
207. How is machinery stopped at pleasure.
208. What of live and dead pulleys?

gradually or in one or more violent efforts; the efforts being entirely the concentrated amount of the previous accumulation. The apparently wonderful powers displayed through the agency of levers and other simple machines, are all a natural consequence of an accumulation of any degree of force into a small space; by which, effects take place that could never have been accomplished by the original force.

254. In consequence of this convenient accumulation of power in machines, plans have been devised for establishing *reservoirs of power*, as they may be called, in connection with moving machinery.

255. A well-known method of accumulating power consists in suspending a heavy body by a chain or strong rope of considerable length—forming what is called by young persons a *swing*. This body may be put in motion by a very small degree of power, and will acquire a vibrating motion like a pendulum. By continuing the impulse as the body returns, it will continually acquire greater and greater force, the arcs through which it moves becoming continually larger, until at last it might be made to overcome almost any obstacle. Upon this principle, the battering rams, or engines for beating down the fortifications of towns in ancient times, were constructed, and the force of their blows was as great as that of a cannon ball; nevertheless, the power of their blows never could exceed the accumulated power of the impulses given to them in order to produce these blows.

256. The forcible expenditure of accumulated power in the swing apparatus, resembles that which is observable in the case of a person occupying several minutes in bending a spring—that is, accumulating power—and then allowing the spring to unbend itself by one violent effort, which effort is nothing more than the giving out of the accumulated power.

257. A boy taking a race to gain force before making a leap, is another familiar example of accumulating power

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209. What of reservoirs of power?
210. What of battering rams?
211. What familiar examples are cited?

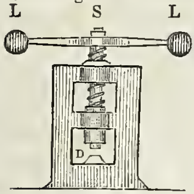
and expending it instantaneously. The boy is gathering up power at every step he runs, and the force of his leap corresponds exactly with the quantity of the power he has acquired.

258. In the same manner, the lifting of a hammer, axe, or other instrument, to an elevation as far as our arm can reach, in order to give a blow with good effect, is a method we naturally pursue to gain an accumulation of power.

259. In contrivances in the arts, power is sometimes accumulated in order to be given out in the form of a rapid and effective blow. This may be done by means of a horizontal bar or lever, poised on a central axis, and loaded at each end with a heavy ball of lead or iron. After communicating to the machine a sufficient power of rotation, it will proceed with an enormous accumulated energy and momentum, till it expend its force either by friction in turning, or upon some fixed obstacle presented to it.

260. The press used for stamping or taking impressions of coins and similar articles from dies, furnishes one of the best examples of the instantaneous expenditure of accumulated power. A press of this kind is represented in figure 79. The apparatus is very simple. It consists of a strong upright frame of iron, with a thick screw S suspended from the upper cross beam, and going through a middle cross beam. In these two beams the screw works freely. The screw is wrought by a horizontal lever bar, poised on a central axis, and loaded at each end with a heavy ball L L. The die lies on the point D below, and the blank piece of metal to be struck is laid upon it. If a coin with two sides is to be impressed, another die is fixed upon the point of the screw. The rapid and forcible pulling round of the lever causes the screw to sink, and by a single rapid crush or blow upon the metal against the die, or dies, the impression is made. The shock of concussion causes the screw to rebound upwards, and the instant a vacancy is left below, the

Figure 79.



212. Explain the diagram, and its use.

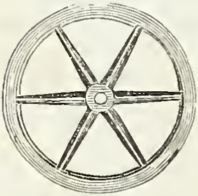
impressed metal is taken out, and a new piece is inserted. By this simple process, coins, medals, ornamented metal buttons, and similar articles, are struck.

EQUALISATION—FLY WHEELS.

261. In most machines, both the moving force and the resistance to be overcome are liable to fluctuations of intensity at different times, during the operation of working. For instance, when a man turns a winch or handle of a piece of machinery, he is apt to relax in his efforts for an instant from loss of strength, or from an inability to keep his attention closely and uniformly fixed to the labour he has to perform. These relaxations cause an irregularity of motion in the machinery, which are detrimental to the machine and to the work performed. Other moving forces are liable to similar irregularities.

262. The irregularities in the motion of machinery, from whatever cause they arise, are remedied by giving to each machine a *reservoir of power*, from which force may be given at all times to equalise the motion according as it may be required. These reservoirs of power are usually in the form of *fly wheels*.

Figure 80.



263. A fly wheel is generally made of iron, and consists of a heavy rim or circumference, joined to a central axis by cross bars or spokes. Figure 80. In most cases it is placed in close connection with the first moving force, the effect of which it equalises in its passage to the machine.

264. Whatever quantity of power is communicated to a fly wheel, the fly accumulates it and gives it forth as may be required, in order to overcome any small variations in the first moving force or in the working of the machine.

265. The power is communicated to the fly wheel at its axle, and thence affects the whole fabric. The motion is

213. What is the nature and use of fly-wheels?
214. Explain the diagram.

at first given in a gradual manner, till it becomes steady. If there were no machine to retard the speed, and the impulsive force continued to be administered, the effects, from centrifugal force, would soon be overpowering. In practice, the friction of the various parts of the machine checks the tendency to over velocity, and when the machine lags, or tends to work irregularly, the gathered momentum of the fly is expended in preserving regularity.

268. The weight, size, and velocity of fly wheels, are regulated by the nature and quantity of the power applied, and the nature of the machinery to be put in motion. There is a certain degree of velocity at which the force employed will produce the greatest effect; and it is of importance to keep this circumstance in view, in the construction of machines.

PRACTICAL MACHINERY CONTINUED—OBSTACLES TO MOTION.

267. Moving bodies, as machines and wheel carriages, are less or more retarded in their velocity by friction, and the resistance of the atmosphere, while vessels moving on water are retarded by the resistance both of the atmosphere and of the liquid in which they are buoyant.

FRICTION.

268. Friction is an effect of the action of rubbing of bodies one upon another.

269. This effect is produced by inequalities of surface. No such thing is found as perfect smoothness of surface in bodies In every case there is, to a lesser or greater extent, a roughness or unevenness of the parts of the surface, arising from peculiar texture, porosity, and other causes; and, therefore, when two surfaces come together, the prominent parts of the one fall into the hollow parts of the other. This tends to prevent or retard motion. In dragging the

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215. What particulars are important?
216. Name the various obstacles to motion.
217. What is the source and influence of friction?

one body over the other, an exertion must be used to lift the prominences over the parts which oppose them, and this exertion is similar to that of lifting or drawing of bodies up inclined planes or over upright protuberances. The effect so caused is called *friction.*

270. Friction acts as a retarding influence in the action of all mechanical contrivances, and a due allowance must in every case be made for it. In many instances it destroys more than a half of the power employed, and seldom destroys less than a third. However small it may be, it sooner or later causes the wearing down and destruction of mechanism, and therefore forms an insurmountable obstacle to the lasting duration of bodies and the perpetuity of motion.

271. The action in overcoming friction being of the nature of lifting or drawing of bodies up inclined planes, gravity is permitted to have an effect in the drawing of bodies upon horizontal planes not perfectly smooth. Thus, *weight* forms an important element in calculating the probable amount of friction of a body.

272. Friction is found to depend on the following circumstances:—1st, The degree of roughness of the surfaces. 2d, The weight of the body to be moved. 3d, The extent of surfaces in certain bodies presented to the action of rubbing. 4th, The nature of the bodies. 5th, The degree of velocity of the motion. 6th, The manner of the motion.

273. *Roughness.*—It is of the utmost importance to smooth the surfaces. An apparently insignificant piece of matter, or even particles of dust, will greatly retard the motion of a body. But there is a limit beyond which it would be imprudent to smooth the surfaces of bodies having a close texture. If the surfaces be highly polished and levelled, the bodies will adhere by the effect of attraction of cohesion, even when the atmospheric air is not entirely expelled from between them, and more forcibly when the air is completely expelled. Practically, roads, railways, and similar bodies, cannot be made too smooth.

274. *Weight.*—Friction from weight differs in different

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218. What circumstances affect friction ?
219. What of roughness, and weight ?

bodies, and depends on concurring circumstances, as nature of surface, and so forth. Friction always increases in exact proportion as the weight increases, when all other circumstances remain the same. Any moving part of machinery, therefore, should be made as light as possible, consistent with strength and durability.

275. *Extent of surfaces.*—Rough bodies are more easily drawn along when their surface of contact is narrow than when they are broad. For example, it is easier to draw two narrow brushes across each other, than two broad ones of the same weight. Friction may, therefore, be diminished in rough bodies by lessening the extent of surfaces in contact. But there is a limit to this diminution. If the moving surface be very thin, and the other soft, the thin surface will plough a groove in the soft one, and thus the friction will be increased, and the machine injured. In the case of smooth hard bodies, extent of surface makes no difference in the friction.

276. *Nature of Bodies.*—It is a remarkable truth that two bodies which are of the same nature, or homogeneous, produce greater friction in movement, than bodies which are different in their nature, or heterogeneous. Thus, iron working against iron, steel against steel, or brass against brass, causes in each case greater friction and wearing of parts, than when iron or steel is made to work against brass. This circumstance is always attended to in the construction of machinery. Frequently, a small piece of leather is adjusted round an axle, to prevent the metals from coming in contact.

277. *Degree of Velocity.*—Friction is a uniformly retarding force, except in the case of small velocities, when it is greater in proportion. The reason for it being greater in small velocities, is, that in these cases, time is allowed for the prominences of the moving body to sink deeply into the hollows of the surface on which it is moving, which has a retarding effect.

278. *Manner of the Motion.*—The least advantageous

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220. How is extent of surface to be modified?
221. What of the nature of bodies, and of velocity?

manner in which one body can be moved upon another, is to cause it to slide or drag. The most advantageous manner, is to cause it to roll or turn. The causing of a body to roll instead of to slide, is one of the chief means of diminishing friction. The opposition presented by inequalities of surface to a rolling wheel, is overcome with ease, in proportion to the extent of diameter of the wheel. On a perfectly horizontal plane, the friction of wheels on the plane is very inconsiderable; the chief seat of friction in such cases, being in the axles working in their sockets.

279. Various plans have been tried to modify the friction of wheels in their sockets. One remedy consists in constantly keeping up a fresh lubrication from small reservoirs of oil placed in the axles or gudgeons, and which supply the deficiency as it occurs. A more effectual plan consists in surrounding the inner sides of the gudgeons with small wheels, upon the rims of which wheels the axle works in turning. These *friction wheels*, as they are called, save the axle from rubbing on the inner surface of the gudgeons, and transfer the friction to their own small axles.

280. Friction is greatly diminished by lubricating the rubbing surfaces with an oily or greasy substance, which substance forms a medium of small soft particles betwixt the bodies, and so prevents the tendency to grind or wear down the surfaces. Water or any similar fluid will also act as a medium to prevent friction, but the effects are only temporary, and would frequently be injurious, as the substance speedily evaporates, and would corrode metals. Practically, fine pure oil is found to be the best unguent for machinery.

281. One of the first considerations on the part of contrivers of mechanism, should be how to provide for and diminish the effects of friction in their machines. For want of forethought on thi important point, thousands of ingenious schemes, which seemed perfect in the form of models and drawings on paper, have been completely frustrated when attempted to be brought into use.

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222. What of rolling and sliding motion ?
223. How is friction modified in wheels ?

USES OF FRICTION.

282. Whatever may be the retarding and frequently inconvenient effects of friction, in reference to the action of mechanism, it is certain that friction is indispensable in the economy of both nature and art, and serves as an essential auxiliary to gravitation. It is a property which is frequently necessary, in order to allow one kind of matter to possess a hold upon another, without actual cohesion. We walk and maintain our erect posture by means of gravitation and action and reaction—in other words, we are held to the earth by gravitation, and our pressure with our feet exemplifies action and reaction—but if there was no such property as friction, we should either stick to the earth by attraction of cohesion, or slide along it as upon the smoothest ice. In order to keep our feet from sliding when on ice, if we received any impulse, we either tie rough substances on our shoes, or scatter ashes in our path; and thus we receive the benefit of friction. It is by friction that rains wear down hills, and that rivers wear away their banks, by which ceaseless process the external configuration of the globe is constantly undergoing a change. The operations in art, of washing, cleaning, scouring, sharpening, polishing, cutting, bruising, beating, and so forth, are all effected less or more by friction. The hold which one fibrous substance has on another, or mutual friction, permits the operations of weaving cloth, twisting ropes and threads, and the tying of one body to another. Thus, friction is of universal service; and the only known instances in nature in which it is not required, and therefore not present, are the movements of the heavenly bodies, which revolve in a vacuum, and are consequently not impeded in their motions.

RESISTANCE OF AIR AND WATER.

283. Atmospheric air and water are fluids of different densities, and both present an obstacle to the motion of solid bodies through them.

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225. Illustrate the uses of friction.
226. What of the heavenly bodies?

284. There is a rule in respect to the resistance presented in moderate velocities, which applies both to air and water. It is, that THE RESISTANCE IS PROPORTIONAL TO THE SQUARE OF THE VELOCITY. For example, a velocity of twenty miles an hour causes a resistance four times greater than a velocity of ten miles an hour, for the square of twenty (which is 20 times 20, or 400) is four times the square of ten (which is 10 times 10, or 100). Thus, by increasing the velocity of bodies through the air or water, we must increase the power in a greater proportion, in order to compensate the loss caused by resistance.

285. Although the above rule is nearly correct for moderate velocities, it deviates considerably from what is observable in the case of great velocities, such as that of a cannon ball. When the velocity is upwards of 1000 feet per second through the air, the quick passage of the body is believed to cause a partial vacuum behind it, which causes a retardation of its motion.

286. Resistance to motion in fluids is greatly modified, also, by the form of the moving body. The form that gives least resistance is nearly that of a parabola, or a form somewhat resembling the breast of a duck, the head of a fish, or the rounded bow of a vessel, sharpened to cleave the fluid through which the body passes.

PRACTICAL MACHINERY CONCLUDED—MOVING FORCES.

287. The sources of power for moving machinery are various, and are employed according to circumstances. Men and animals, water, wind, and steam, are the principal sources, or, as they are called, *agents* of force. Men and animals operate by muscular energy; water acts by its momentum and gravity; wind by its pressure when in a state of motion; and steam, by the expansive energy of heat. There are also other agents of power in nature; such as magnetism, galvanism, electricity, and capillary

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227. What is the rule of resistance by air and water?
228. How with a cannon ball?
229. How does form effect motion in fluids?
230. Name the agents of force, and their mode of action.

attraction; but these have hitherto produced motion only on a limited scale.

HUMAN LABOUR.

288. The muscular energy of men forms the most insufficient, or the weakest, of all the prime moving forces. Human labour is very limited in its compass, and is the least to be depended on for regularity. The power exerted by one man is comparatively small, and it is both inconvenient and expensive to cause a large number of individuals to unite their powers in a continued or concerted effort.

289. The power of a man to produce motion in a machine, weight, or resisting body, varies according to the mode in which he applies his force, and the number of muscles which are brought into action. In the operation of turning a winch or handle of a wheel, as for example that of the crane, figure 63, a man's power changes in every part of the circle which the handle describes. His power is greatest when he pulls the handle upward from the height of his knees, next greatest when he pushes it down on the opposite side, though here the power cannot exceed the weight of his body, and is therefore less than can be exerted in pulling upward. His power is weakest when at the top and bottom of the circle, where the handle is pushed or drawn almost horizontally.

290. A man can exert the greatest active strength when he is at rest in his person (that is, not walking), and when he pulls or lifts a body upwards from his feet, because the strong muscles of his back, as well as those of his arms and legs, are then brought advantageously into action, and the bones are favourably situated, by the fulcra of the levers being near to the resistance. Hence, the action of rowing, or pulling oars, is one of the most advantageous modes of muscular exertion. In that operation, the whole frame exerts itself in the most favourable manner; and no method which has been devised for propelling boats by the labour of men, has hitherto superseded it.

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231. What of muscular power?
232. How does this vary as in turning a crank?
233. How may the greatest strength be exerted?

291. It is usual, in estimating the amount of power which can be exerted by animals, to reckon it by the weight which the animal can lift in a given length of time to a given height. By this standard, it is computed that a man of ordinary strength ran raise a weight of 10 pounds to the height of 10 feet once in a second, and continue this labour for 10 hours in the day. This is supposing him to use his force under common mechanical advantages, and without any deduction from friction.

292. All such estimates as this, however, are exceedingly illusive. The ability for exercising power varies in different countries, and depends greatly on exercise and diet. Therefore, no *practically* useful calculations can be made regarding it.

293. Human strength, as has been said, can be exerted with greatest effect in lifting from the ground, and pulling as with an oar. But this species of action produces exhaustion; and hence the advantage is neutralized by a certain disadvantage. The way in which the greatest effect can be produced by human labour, with a moderate degree of fatigue, is simply to allow the weight or gravity of the person to work. For example, let a man walk up a ladder to a certain height, and then stepping into a bucket which is attached to a cord and pulley, permit himself to sink with the bucket to the ground, drawing up a load at the other end of the cord. Whatever be his weight, he will be able to raise at each descent a load nearly as great; and therefore, by such a plan, would, in the course of a day, raise a great deal more weight of material to the top of a house, than by the common process of carrying up a mass of matter in his hands or on his shoulders.

294. In giving effect to the gravity of the person, no exertion is used; and the only source of fatigue is that of walking up an inclined plane to obtain a due elevation. According to the principle defined in paragraph 135, the expenditure of exertion in ascending inclined planes, is not according to the degree of inclination, but according to the

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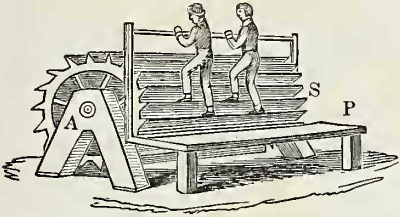
234. What estimate has been made of animal power?
235. What illustrations are cited?

elevation reached; this is agreeable to the rule of mechanics mentioned in paragraph 17, namely, that a small force exerted for a long period of time is equivalent to a great force exerted for a short period of time. Thus, nearly the same degree of animal fatigue is incurred by reaching the same elevation in the same time, whatever be the inclination of the ascent.

295. In walking on a perfectly horizontal plane, the gravity of the person, in ordinary cases, is not felt; for the fabric of the body is so nicely balanced, and the weight so generally borne by the different parts that we are hardly conscious of the exertion. When we try to ascend a hill, we begin to feel that our gravity retards, and consequently fatigues us, for we are pulling against the force of terrestrial attraction. But when we commence descending a hill, we feel that we are greatly assisted by our gravity—that is, we are allowing attraction to pull us. We are also assisted in descending, by an acquired momentum in our person.

Figure 81.



296. The moving power given to machinery by the mere gravity of the person, is seldom used except in the case of involuntary labour at the tread-mill. A tread-mill is a large broad wheel with steps all round on its circumference, and on which steps men are compelled to ascend, holding on by a fixed bar or rail in front. The weight of the men turns the wheel, which, by turning an axle, gives motion, if necessary, to certain machinery. The tread-mill thus forms a revolving or endless stair. Figure 81 represents one of these machines in operation. A is the axle, S are the steps, and P is a fixed platform in front of them.

297. It is evidently disadvantageous to employ human

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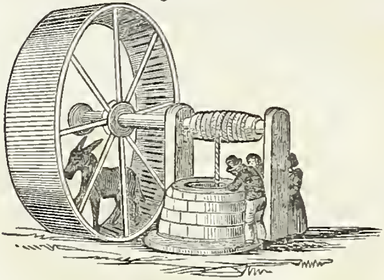
236. What of ascending and descending a hill?
237. Explain the tread mill.

labour as a moving power, except in cases in which the force required is so small as not to require further aid, or where skill as well as muscular energy is necessary. The human being has been designed for executing higher duties than those which can be adequately performed by the lower animals, and by the agency of inanimate forces.

Figure 82.



298. The power of the ass is sometimes employed as a moving force, in operations not requiring great labour, and on a principle similar to that of the tread-mill. At Carisbrook Castle, in the Isle of Wight, an ass was lately employed to move a machine acting like a windlass for drawing water from an exceedingly deep well. The animal acted entirely by giving effect to its weight, as represented in figure 82

HORSE'S POWER—DRAUGHT.

299. Horses and oxen are used, in all countries where they exist, as agents of force. Horses are more valuable for this purpose than oxen, because they are generally more tractable, and otherwise better suited for the labour. Oxen are used only for draught.

300 A horse employs two forces in drawing—the force of his muscular energy exerted against the resistance of his hind legs and feet, and the force of his weight or gravity. Power of draught is estimated according to the constitutional strength, height of breast from the hind feet, and weight of the animal.

301. The force of a horse diminishes as his speed

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238. What does the last diagram show?
239. What of oxen and horses and their forces?

increases beyond a certain limit. If the load that he can pull, when moving at the rate of two miles in an hour, is represented by 100, that at three miles in an hour will be 81—at four miles in an hour, 64—at five miles in an hour, 49—and at six miles in an hour, 36.* In this way the draught of a horse continues to diminish, till he attains his greatest speed, when he can barely carry his own weight.

302. A horse exerts his power most advantageously, when walking at the rate of about four miles in an hour. This advantageous rate of speed, however, does not apply in the case of short efforts. In these, a rapid motion, to get at once over the difficulty, is most advantageous for the muscular energy.

303. There are various estimates of a horse's power, but that of James Watt is generally adopted as the standard. The measure of a horse's power, according to Mr. Watt, is, that he can raise a weight of 33,000 pounds (for instance, drawing it over a pulley) to a height of one foot in a minute.

304. In comparing the strength of horses with that of men, it is estimated that the force of one horse is equal to that of five men. But this estimate is liable to certain important exceptions. Much depends on the manner in which the exertion takes place.

305. Any body moving forward on a smooth horizontal plane, can be drawn with the least possible force, when the line of draught is straight in a horizontal line from the power to the point of resistance. But a horse, in drawing, can use his weight and muscular energy with greatest advantage when the line of draught inclines from the load upward to his breast. Thus, the convenience of the horse must always be consulted in practical operations.

306. A horse, also, can pull a wheeled carriage with greater advantage when the wheels are large than when they are small, because large wheels get most easily over

* These proportions are given by Professor Leslie, and are confirmed by the observations of other experimental mechanics.

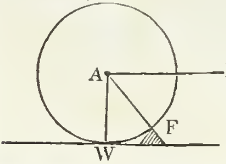
240. How is the force of a horse calculated ?
241. Mr. Watt's estimate.
242. How does it compare with the power of man ?
243. How should the line of draught be regulated ?

obstacles lying before them. This is an evident truth, but it can be proved by an appeal to the principle of the lever.

307. The operation of drawing a wheeled vehicle, presents an example of lever action of a peculiar kind. The load of the vehicle, or the *weight*, presses on the nave or axle of the wheel, and the direction of its action thence passes down in a straight line to the plane on which the vehicle rests. The direction of the power is a line from the moving agent to the axle. If the plane be perfectly smooth, the *fulcrum* is identified with the point on which the weight presses on the ground. If any obstacle be placed before the wheel, then, that obstacle, at the instant of contact, becomes the *fulcrum*

308. Figure 83 represents a wheel, with an obstacle, which we may suppose to be a stone, lying before it. The line of draught P A is the direction of the power. A horse may be supposed to be pulling at P. The line A W is the direction of the weight. F is the obstacle, or fulcrum, upon which the power has to act. A line from A to F may represent the lever, having the fulcrum F at one extremity, and the power and weight applied to the other extremity A. The apparatus is thus a lever of oblique action with a single arm. According to the rules laid down for estimating the power of bent levers, the arm of power is an ideal line drawn at right angles from the line A P to F, and the arm of weight an ideal line drawn at right angles from the line A W to F. The mechanical advantage is calculated from these two ideal lines. By increasing the diameter of the wheel, these ideal lines increase, but that of the power increases in the greatest proportion, and hence the advantage of increasing the diameter of wheels.

Figure 83.



309. It is customary to place small wheels before large ones in four-wheeled carriages. This is done only for the sake of convenience in turning the vehicle ; if the front

244. What of wheels and their motion ?
245. Explain the diagram.

wheels were made as large as the hind ones, the carriage would be more easily drawn.

310. In yoking several horses, one before the other, to ploughs or wheeled carriages, it is of importance to cause the line of draught of all the horses to proceed in a straight line to the point of resistance, or as nearly so as is convenient. The resistance of the plough is in the sock or cutting part in the earth, and the resistance of the load in wheeled carriages, is at the axles. The distance of the animals from the machine they are drawing, is of little consequence, provided each horse is able to exert his force directly in a line to the resistance.

311. Horses draw with best effect when they are yoked singly or abreast. In yoking them one before the other, a portion of their force is generally expended uselessly, if not mischievously, in hampering each other. When a horse draws a four-wheeled carriage, the line of his draught should go to a point between the two axles, and come over the front axle. The same rule holds with two or more horses in four-wheeled vehicles.

312. Wheels have least friction where they are narrow in the rim, but this is supposing the road to be hard and smooth. In cases of great weights, and when the roads are not very smooth or hard, broad wheels are the best for both safety and draught. Wheels which are perfectly straight or upright are pulled with less exertion than wheels which are of a *dished* form—that is, with the spokes sloping to the rim; but the dished form is of use in widening the base and preventing overturning; it is also particularly useful where the road is inclined to one side, as the spokes of the lower wheel, which then support more than half the weight, are more nearly in a vertical direction, and therefore resist the pressure with the greatest effect; so that when the load is thus increased upon them, their resisting power is at the same time increased.

313. When the load is suspended on springs, the shocks

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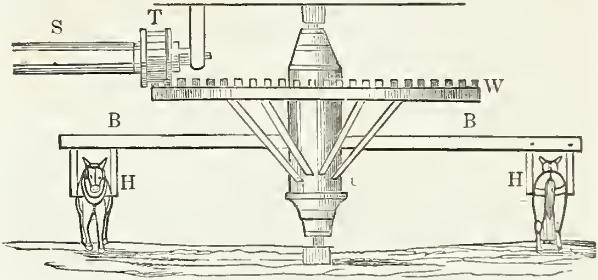
246. Why the difference in the wheels of carriages?
247. What of the point of resistance in draught?
248. What of more horses than one?
249. What of a variety in wheels?

caused by friction in movement are lessened—that is, the force of the concussions is spent upon the elasticity of the spring, a circumstance of great convenience to passengers in carriages. The elasticity, also, preserves equability of weight to the horse. At every jolt over a protuberance, without springs, the load receives a momentum in descending, which on being checked gives a shock to the animal in the shafts; whereas, in using springs, the weight has always a comparatively equal pressure.

314. Horses communicate moving power to machinery, by being yoked to a horizontally turning beam or wheel, and walking in a circle. The motion of the beam or wheel, by acting on a pinion and shaft, moves the machinery. Many mills are turned in this manner. To give full advantage to the capacity of the horse, the circle should not be less than from thirty to forty feet in diameter.

Figure 84.



315. Figure 84 represents the action of horse power upon a mill. U is an upright axle working on pivots, from which axle a beam B B is projected, and into which two horses H H are yoked. W is a horizontally moving wheel on the axle, which wheel turns a trundle T fixed to the shaft S. The turning of the shaft moves the machinery.

316. The same principle applies with respect to the employment of horses and other animals, as agents of force, as

250. Of what advantage are springs ?
251. How do horses best move in machinery ?
252. Explain the diagram.

that which applies to human labour (paragraph 297.) An animal is only employed advantageously when he is caused to do work which could not be as conveniently executed by inanimate forces. In all cases in which inanimate forces can be conveniently substituted for animal power, the application of the animal is not legitimate, because only its weight and muscular energy are brought into operation, and its sagacity, which is frequently a valuable part of it, lies unemployed.

WATER POWER.

317. Water acts as a first mover by the force of its gravity or weight; and also in some cases by its momentum or impulsive power. It is applied by causing it to fall or flow upon the outer part of a wheel, which turns with the force.

318. Water power, if to be had in a sufficient quantity, is preferred to all other powers, in consequence of its simplicity of action, extraordinary cheapness, and steadiness.

319. The mode of applying water power to a wheel depends on the extent of the fall, or the height of the stream at the point where it can be properly applied. It is of importance to have as great an extent of fall as possible; but at the same time, a certain declivity must be left below the mill, in order to allow the water to flow freely away, and not obstruct the wheel in its motion.

320. Two chief kinds of water-wheels are used according to the extent of the fall, and the nature of the stream. When the water cannot be made to approach the wheel, higher than a point opposite the middle of the wheel, a *breast wheel* is used. The water is brought by an artificial channel and permitted to flow or fall into buckets fixed in the outer circumference of the wheel. The weight of the water in the buckets, presses down the wheel and causes it to turn. When the buckets come to the bottom in revolving, they let the water flow from them, and go up empty on the other side, ready to be again filled.

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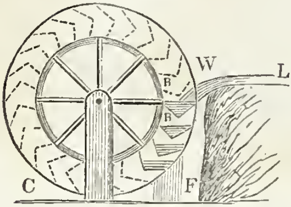
253. What is said of animal agency in machinery ?
254. What of water power and its advantages ?
255. How is it best applied ?
256. Describe both kinds of water-wheels.

321. Figure 85 represents the action of a breast water-wheel. W is the water flowing from a channel L into the buckets B B, which are supposed to be seen through the sides of the rim; these buckets are emptied on coming down to F, and the water flows away in the channel C. From W to F is reckoned the height of the fall. The axle of the wheel in this case turns the machinery; but sometimes the wheel has teeth round its circumference, which, working on a pinion, turns the machinery.

Figure 85.



322. When the fall is considerable, or when the water can be made to approach by a channel on a level with the top of the wheel, an *overshot wheel* is used. The water is allowed to fall into the buckets at the top, so as to act much more advantageously than if it fell at a lower level. It is seldom that streams can be conveniently brought to operate in this advantageous manner.

323. Water power. acting either by breast or overshot wheels, is a much more effective and steady agent of moving force than wind. Windmills are used only in cases in which perfect regularity and constancy of motion are not required, and where water cannot be obtained at a sufficient height to form a fall.

STEAM POWER.

324. Water boils at 212 degrees of Fahrenheit's thermometer, under the common atmospheric pressure; and the application of fire, after it reaches the boiling point, causes it to fly off in the form of vapour or steam.*

325. A cubic inch of water produces almost exactly a cubic foot of steam, or 1728 cubic inches. In its expansion therefore it exerts enormous force, and this circumstance has rendered it valuable as a source of power.

* See LAWS OF MATTER AND MOTION, in which the subject of heat in application to water is fully treated of.

257. Explain the diagram.
258. What of wind as an agent of force?

326. Steam is applied to machinery by means of a boiler and an apparatus called the *steam-engine.* Steam-engines are of different constructions, and improvements and simplifications are continually taking place in their character and mode of working. The power exerted by steam-engines, is estimated according to the horse powers to which they are equal, and which there are certain rules for calculating.

327. There are two distinct kinds of engines, namely, *high-pressure* or *non-condensing*, and *low-pressure* or *condensing*. The high-pressure engine is the most simple in its construction. The steam, generated in a boiler, rushes through a tube to the cylinder, which is a close round vessel like a barrel. It enters the cylinder at two openings, one at the bottom and the other at the top. The steam which enters at the lower opening drives up a round object or plug, fitting nicely to the cylinder, and called the piston, to the top, whence it is driven down again to the bottom by the steam which enters at the upper opening; the steam used in both cases being withdrawn to allow the action. An external rod from the piston, thus driven up and down, passes out of the cylinder at a small orifice at the top, and affects the beam, which, turning a crank, moves the machinery. In this kind of engine, the steam, on performing its office of depressing and raising the piston, is allowed to escape into the atmosphere; and the engine is called high-pressure, because, steam of a high degree of pressure has to be employed to counteract the pressure of the atmosphere on the escaping steam.

328. The low-pressure or condensing engine is supplied with steam in much the same manner, but the mode of withdrawing and destroying the used steam from the cylinder is totally different. As soon as the steam, which rushes in at the lower opening of the cylinder, has driven the piston upwards, it is instantaneously abstracted or withdrawn into a separate vessel below, called the condenser, where it is condensed by a squirt of cold water, and runs off into a cistern; from which cistern the water in a warm state is

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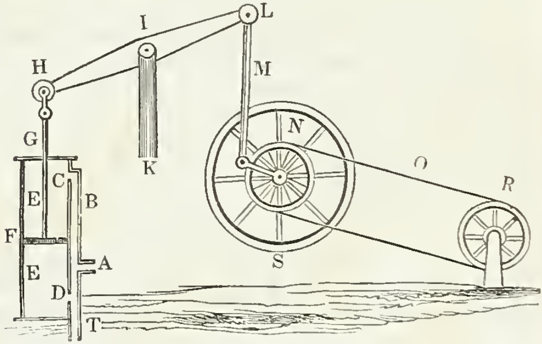
259. What is said of steam?
260. What principle of steam is the source of power?
261. By what means is it applied, and how calculated?
262. Describe a high-pressure engine, and why so named?

pumped into the boiler to make new steam. The same process takes place with the steam which drives the piston downwards. The abstraction of the steam into the condenser is effected by an air-pump (wrought by the engine), which, at the proper instant of time, pumps out the water produced by the condensed steam, and that of the condensing jet, and also any air that may collect, and forms a partial vacuum in the condenser. As this vacuum presents no obstacle to the action of the piston, in other words, as the steam is not opposed by the atmosphere in making its escape from the cylinder, the steam requires to be of comparatively small force—much smaller than if the pressure of the atmosphere had to be overcome; it is therefore called a low-pressure engine.

329. The low-pressure or condensing engine, just noticed, is also called a *double-acting* engine, because its piston is driven both up and down by steam. There are low-pressure engines called *single-acting* engines. These have the piston acted upon by steam only in the down stroke, the up stroke or return of the piston, being produced by the action of a counterweight on the farther extremity of the beam.

330. Figure 86 represents a rudimental outline of the

Figure 86.



263. What of the low-pressure engine, and the difference.
264. What difference between double and single acting engines?
265. Explain the diagram.

action of steam power, whether in high or low-pressure engines. A is the pipe by which the steam is conducted from the boiler to the cylinder E E, by means of the pipe B into the cylinder E E at the upper opening C and the lower opening D. F is the piston with a rod G going up to the end of the beam H. This beam moves up and down on a central axis I. From the extremity of the beam at L, a shaft M goes down to the crank on the pulley N, which it turns. From N a belt O is carried to the pulley R, and a shaft from this pulley moves the machinery. S is a fly wheel working close beside the crank pulley. The pipe T is the path for the escape of the steam from the cylinder after performing its office. At the different openings in the communication pipes, there are little doors or valves, which are opened and shut as is required to admit or allow the escape of the steam; but these valves, and also many minor parts of the mechanism, are for the sake of clearness not marked in the figure, and the steam engine should be seen in actual operation, if a perfect idea of the apparatus is desired.

331. Steam power, when properly organized, possesses the quality of great steadiness of action, in which it almost equals water power. It is therefore adapted for turning all kinds of machinery, and may be employed in every imaginable situation where fuel and water exist. The most wonderful of its achievements is the propulsion of vessels at sea, and vehicles on railways upon land.

332. The steam power at present employed in Great Britain and Ireland, is equal to about 8,000,000 of men's power, or 1,600,000 horse power. It is calculated that a horse requires eight times the quantity of soil for producing food that a human being does; if, therefore, horse power were made to supersede steam power, additional food for 1,600,000 horses would require to be raised, which would be equal to the food of 12,800,000 men. [As the amount of steam power employed in America is more than ten times that in Great Britain and Ireland, these calculations must all be increased tenfold, if we would approximate the importance of this agent in our country.]

333. It is in consequence of the improved mechanical

266. To what useful purposes is steam applied?
267. What calculations are made?

arrangements, and employment of inanimate forces in Great Britain, that that comparatively small country is enabled to manufacture goods cheaper, and with greater profit, than can be done by the largest and most populous countries in which mechanism is imperfect, and labour performed exclusively by living agents.

334. The profits of manufacture so produced, spread their beneficial influence over the whole mass of society, every one being less or more benefited. Thus, almost all the luxuries and comforts of life, all the refinements of social existence, may be traced to the use of tools and machinery. Machinery is the result of mechanical skill, and mechanical skill is the result of experience and a long course of investigation into the working of principles in Nature, which are hidden from the inattentive observer. Much of the present mechanical improvement is also owing to the pressure of necessities, or wants, which have always a tendency to stimulate the dormant powers of man. What are to be the ultimate limits and advantages of mechanical discoveries, no one can foresee. The investigation of natural forces is yet far from being finished. Every day discloses some new scientific truth, which is forthwith impressed into the service of mankind, and tends to diminish the sum of human drudgery and suffering. In this manner, therefore, are we usefully taught, that the study of Nature forms a never-failing source of intellectual enjoyment, and that "KNOWLEDGE IS POWER."

The subject of the next Treatise is HYDROSTATICS, or the LAWS OF FLUIDS.

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268. Name some of the advantages derived from it.
269. Are not still further improvements probable?
270. To what source are we to look for their discovery?

THE END.

ELEMENTS

OF

NATURAL PHILOSOPHY.

PART III.

HYDROSTATICS, HYDRAULICS,

AND

PNEUMATICS.

CHAMBERS' EDUCATIONAL COURSE.

INTRODUCTORY OBSERVATIONS

BY

THE AMERICAN EDITOR.

With this third book of Natural Philosophy, the teacher will be able to conduct his pupils to an easy acquaintance with the most intricate and difficult features in the whole science, the two former books having removed every obstacle in the way of the learner. The laws of matter and motion, and the elements of practical machinery, and moving forces with reference to solids, having been made plain, the laws of fluids will much more readily be understood than if previously studied.

Hydrostatics, or the science of fluids at rest; Hydraulics, or the science of fluids in motion; and Pneumatics, or the science of air and gaseous fluids, are the successive topics of this volume. Their kindred character and striking analogies render them appropriate subjects to be considered together, while their great practical importance in domestic economy and the business of life, would seem to commend them to young people, as having special claims upon their attention.

The catechetical questions on every page will be found to be thoroughly analytical of the entire volume, and the answer should be required in the words of the text at first, and afterwards expressed in other terms, and with other illustrations than those found in the book. For this purpose, the teacher should, in his discretion, vary the questions and call for other examples.

A class thus instructed will be able to exhibit proofs of their actual knowledge in these departments, by once going through this book, which at an exhibition would astonish those who should witness it, without being acquainted with the facilities which this volume furnishes to the learner by its simplicity and skilful adaptation to the juvenile mind.

With such views, it is earnestly recommended to the practical teachers of our common schools, by

THE AMERICAN EDITOR.

PREFACE.

THE present Treatise, comprehending HYDROSTATICS and HYDRAULICS (or, conjointly, HYDRODYNAMICS), also PNEUMATICS, forms the third department in Natural Philosophy.

The Pupil, having been made acquainted with the Laws of Matter and Motion and with Mechanics, is now introduced to a knowledge of the LAWS OF FLUIDS, both as respects liquid and aëriform bodies. By uniting Hydrostatics, Hydraulics, and Pneumatics, in one treatise, the whole subject of fluids is at once brought before the mind, and is thereby calculated to make a more forcible and agreeable impression, than if, as according to custom, it were divided into separate books.

In this, as in the preceding treatises, very great pains have been taken to render the language simple and intelligible, so that the learner may find at least no technical difficulty in his path. The sentences and paragraphs are likewise written and arranged in such a manner as to form a progressive series of distinct propositions, relieved from extraneous verbiage, and suitable alike for the study of the Pupil, and as the subject of a searching examination by the Master.

CONTENTS.

NATURAL PHILOSOPHY.

HYDROSTATICS AND HYDRAULICS.

GENERAL DEFINITIONS.

1. Matter exists in three principal forms—solid, liquid, and gaseous or aëriform. These forms respectively, and the various modifications of them, are the immediate result of certain principles of attraction and repulsion operating on the atoms or particles of which matter is composed.*

2. The solid, liquid, and aëriform varieties of matter, assume a position on our globe corresponding to their heaviness or density in a given volume—the solid sinks lowest, and composes the chief mass of the earth; above the solid lies the liquid variety, in the form of the ocean, rivers, and lakes; and above all is the atmosphere, consisting of an expanse of aëriform matter, which wraps the whole earth round to an elevation of from forty-five to fifty miles above the highest mountains. In this great ocean of air, loaded less or more with particles of moisture from the liquids beneath, we live, breathe, and move, and plants grow and receive an appropriate nourishment.

3. Though differing both in substance and appearance, the liquid and aëriform varieties of matter resemble each

* The principles of attraction and repulsion are explained in the Laws of Matter and Motion, from paragraph 34 to 124, and must be already familiar to the pupil. As forming the basis of physical science, they ought to be thoroughly understood.

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1. In how many forms does matter exist?
2. How are they arranged in the globe?

other in many of their properties and tendencies, and constitute the class of bodies termed *fluids*.

4. Fluids signify bodies which will flow, or whose component particles are easily moved among each other.

5. Some fluids are so thick and viscous, or sticky, that they can scarcely flow, as tar, honey, and some metals in a state of fusion ; others flow with ease, as water and distilled spirits ; while others are so light and volatile, as to be impalpable to the touch and invisible to the eye, as pure atmospheric air and various gases.

6. It is common to divide fluids into two kinds—non-elastic fluids and elastic fluids ; that is, fluids which cannot be compressed into a smaller bulk, and those which are susceptible of compression. The non-elastic fluids are water and all other varieties of liquid bodies ; but recent experiments prove that the term is not strictly applicable to them. It has been found that water may be compressed in a confined vessel, to a small extent, by means of a very great pressure, and it is certain that water at a considerable depth in the ocean is more dense or compressed than at the surface ; water, consequently, is an elastic substance ; but as it can be compressed only with very great difficulty, the term non-elastic fluid is not altogether inappropriate.

7. Atmospheric air and all gases are elastic. They can, with little difficulty, be compressed into a much smaller volume than they ordinarily possess ; and when the pressure is removed, they return to their original bulk. Some gases may be compressed to such an extent as to assume the form of liquids and solids ; in other words, from the condition of being perfectly invisible to the eye, they can be made to appear as a piece of solid matter, which may be touched and handled.

8. In treating the subject of fluids, it is convenient to refer in the first place to those which are of the liquid form, and afterwards to those which are elastic or aëriform.

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3. Define fluids, and their variety.
4. How are fluids divided ? and what of compressibility ?
5. Name the peculiarities of elastic fluids.

9. Pure water, at an ordinary temperature, furnishes the most suitable example of liquid bodies.

10. Water also gives the name of the department of science which includes the laws of liquids. Thus, HYDROSTATICS, from two Greek words signifying *water* and *to stand*, treats of the weight, pressure, and equilibrium of liquids in a state of rest; and HYDRAULICS, from two Greek words signifying *water* and *a pipe*, treats of liquids in motion, and the artificial means of conducting liquids in pipes, or raising them by pumps.

HYDROSTATICS.

11. In ancient times water was believed to be an element or simple substance in nature. It is now ascertained by experiment that water is not an elementary body, but is a substance composed chiefly of two gases in a state of chemical union, and into these gases it can be resolved by an artificial process. The investigation of this subject belongs to CHEMISTRY.

12. As a liquid, water consists of exceedingly small particles or atoms of matter in mechanical combination.

13. The exact nature and form of the atoms composing water are not satisfactorily known, in consequence of their exceeding smallness. They may be compared to very small particles of sand, cohering slightly, and easily slipping or sliding over each other. Whatever may be the nature and form of these exquisitely fine atoms, it is certain that they can adhere firmly together so as to assume the form of a solid, as in the case of ice; and be made to separate from each other, and disperse through the thinner fluid of the atmosphere, in the forms of steam, clouds, or mist.

14. Thus, IMPERFECT COHESION OF ATOMS OR PARTICLES is a property common to all fluids.

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6. Define Hydrostatics and Hydraulics.
7. What of the composition of water?
8. What of the atoms of water and their changes of form?

15. The atoms composing water, being in closer union than those of air, are observable as a mass, and palpable to the touch. When the hand is dipped into them, and then withdrawn, a certain quantity of the atoms is brought away on the surface of the skin; and this adhesion of the particles of water (caused by attraction of cohesion) is what we in ordinary language call *wetness*. Certain substances, as is well known, absorb water to a great extent; in such cases, the minute particles of the water merely penetrate and fill up the crevices in the substance.

PRESSURE EQUAL IN ALL DIRECTIONS.

16. Solid bodies, as a stone, or piece of metal, or wood, have a natural tendency to press only in one direction, that is downwards, or in the direction of the earth's centre, in obedience to the law of terrestrial attraction.

17. Water has a similar natural tendency to press downwards, and from the same cause; as for example, when a jug of water is spilled, the water is seen to fall in a stream to the ground.

18. Water, however, is governed by a law of pressure, independently of this general law of gravitation. This peculiar or independent law consists of the tendency in the particles of any mass of water to press equally in all directions.

19. PRESSURE EQUALLY IN ALL DIRECTIONS may be considered as the first or great leading law in reference to water, and generally all fluids, liquid and gaseous.

20. The pressure equally in all directions is a result of the exceeding smallness of the individual particles, and of the perfect ease with which they glide over or amongst each other.

21. To exemplify equal pressure, fill a leathern bag with water, and then sew up the mouth of the bag so

. Give an example of their cohesion, and absorption
10. How is gravitation modified in water?
11. What is the law of pressure in all fluids?
12. Give the reason, with an example.
13. Explain the example cited.

closely that none of the water can escape. Now, squeeze or press upon the bag so as almost to make it burst. The pressure so applied does not merely act upon the water immediately under the point of pressure, but acts equally upon every particle of water in the mass—the particles at the centre being as much pressed upon as those at the outside; and it will be observed that the water will squirt out with equal impetuosity at whatever part you make a hole in the surface.

22. In this, as in all similar cases, there is a transmission of pressure throughout the mass. Each particle presses on those next it; and so, by the force communicating from particle to particle, the whole are equally affected.

23. In the case of water lying at repose in an open vessel, the tendency to press equally in all directions is not observed to act upward, because the gravity of the mass keeps the water down; but on pressing upon the surface of the liquid, we observe that it rises against the compression, or tries to escape in any way it can. To take another example—if we plunge our hand into a vessel of water, we displace so much liquid, and cause it to rise higher up the sides of the vessel. In this case, the water is observed to rise without any reluctance; it as readily presses upward as downward.

PRESSURE IN PROPORTION TO HEIGHT.

24. Although it is a property in fluids to press equally in all directions, the degree of intensity of pressure in any mass of fluid is estimated by the vertical height of the mass, and its area at the base.

25. PRESSURE OF WATER IN PROPORTION TO ITS VERTICAL HEIGHT AND ITS AREA AT THE BASE, is therefore a second leading feature in the laws of water.

26. In other words, the pressure of a column of water does not depend on the width or thickness of the column, but on its height and extent of its base or lower part.

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14. What other illustrations are given?
15. How is the degree of pressure estimated?

27. The whole of any fluid mass may be imagined to consist of a number of columns of an inconsiderable thickness, which stand perpendicularly on the horizontal base of the containing vessel, and press the base of the vessel with their respective weights. The pressure, then, if the height of the fluid be the same throughout, is as the number of columns, and this number is according to the area of the base. Consequently, in vessels whose bases differ as to area, and which contain fluids of the same density, but different heights, the pressure will be in the compound ratio of the bases and heights.

28. If the columns of which a fluid mass was supposed to consist, were formed of particles lying in perpendicular lines, the pressure of the fluid would be exerted on the bottom of the vessel only; but as they are situated in every irregular position, there must of consequence be a pressure exerted in every direction; which pressure must be equal at equal depths. For if any part of the whole mass were not equally pressed on all sides, it would not move towards the side on which the pressure was least, and would not become quiescent till such equal pressure was obtained. The quiescence of the parts of fluids is therefore a proof that they are equally pressed on all sides.*

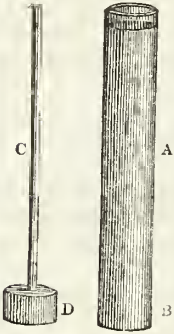

Fig. 1.

29. Several interesting experiments may be made to prove that the pressure of water is in proportion to its height and width of base.

30. Figure 1 represents two vessels of equal height, the same width of base, but of different shapes otherwise. One, AB, is of equal thickness from bottom to top; the other, CD, is a tall narrow tube connected with a broad base. If

* These definitions, in paragraphs 27 and 28, are given by Nicholson, in his Introduction to Natural Philosophy.

16. What method of calculation is named?
17. What does the quiescence of fluids prove?

both be filled with water to the same height, the pressure upon any part of the sides of either will be alike powerful. The pressure against the inside of the narrow tube at C will be as great as against the inside of the much wider tube at A—the mere width of column making no difference in the degree of pressure.

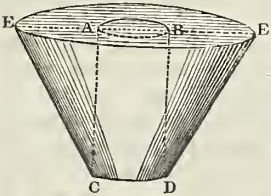

Fig. 2.

31. Another example.—Figure 2 represents a vessel with a broad top EE, tapering to a narrow base CD. The dotted enclosure ABCD represents an ideal column of water the width of the base. The vessel is supposed to be filled with water to the surface EE. Yet the base or bottom sustains no more pressure than that described by the ideal column ABCD; for the other parts of the contained fluid can only press the column ABCD, and also the sloping sides laterally, and therefore do not contribute to the increase of the weight or pressure on the bottom CD.

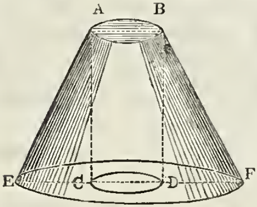

Fig. 3.

32. If we take a vessel of the same capacity, but with a broad base, as in Figure 3, the pressure on the bottom is very different. In this case the base EF sustains a pressure equal to the weight of a column whose base is EF, and height equal to AC; for the water in the central column ABCD presses laterally or sidewise, with the same force as it does on the part on which it stands, and thus an uniformity of pressure is established over every part of the bottom.

33. From these two cases combined, the reason is evident why fluids contained in the several parts of vessels remain everywhere at the same height; for the low-

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18. Explain the diagrams, and the principle of each.
19. What of the first diagram?

est part where they communicate may be regarded as the common base; and the fluids which rest thereon are in equilibrio then only, when their heights are equal, however their quantities may vary.

34. We may prove the truth of these propositions in various ways. Let ABCD, Figure 4, represent a cylindrical vessel, to the inside of which is fitted the cover G, which, by means of leather at the edge, will easily slide up and down in the internal cavity, without permitting any water to pass between it and the surface of the cylinder. In the cover is inserted the small tube EF, open at top, and communicating with the inside of the cylinder below the cover of G. The cylinder is filled with water, and the cover put on. Then, if the cover be loaded with the weight, suppose of a pound, it will be depressed, the water will rise in the tube to E, and the weight will be sustained. In other words, a very small quantity of water in this narrow tube will press with a force as great as if the vessel were of the dimensions KLCD, instead of ABCD. By filling the tube to F, a force will be gained sufficient to balance additional pound weights on the cover G, and as great as could be conferred by a vessel of equal breadth all the way up to F.

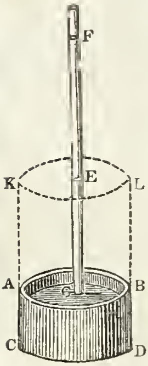

Fig. 4.

35. Water, in its pressure equally in all directions, presses upwards as well as downwards. This is seen in the above experiments. Take Figure 4 as an example. The water in the vessel ABCD, when the tube is filled, presses, as has been said, with a force equal to that of a column of water of equal breadth all the way up to F. This can only be in consequence of the water in the vessel ABCD pressing violently upwards against the cover G, which violence causes a corresponding reaction on the bottom of the vessel. This reaction, then, is equivalent to

20. How is the equilibrium of fluids explained?
21. Explain the next diagram, and its use.

vertical height. To use a figure of speech, the water in the vessel is in the condition of a man pressing equally upwards with his shoulders and downwards with his feet at the same time; and the more he is acted upon by weight above, the more powerfully does he exert his pressure in both directions.

36. The great force which may be exerted by a small but high column of water, is further exemplified by a tube of from twenty to thirty feet in length fitted into the end of a cask, as in Figure 5. One pouring in water sufficient to fill the cask, and also the tube to its summit, so great a strain will be made on the hoops of the vessel, that it will in all likelihood burst; in effect, the pressure on the sides of the cask will be equal to that of a column as wide as the cask and as high as the tube; and for this degree of pressure, casks are not usually prepared. If we suppose that the area of the tube be no more than the twentieth of an inc , and the tube altogether contain only a pound of water, the pressure caused by this inconsiderable quantity of liquid will be equal to a pound on every twentieth of an inch in the cask; and for this enormous degree of pressure, no cask is prepared.

Fig. 5.

37. An instrument called the hydrostatic bellows has been constructed to exemplify the effect produced by the pressure of a small column of water. As represented in Figure 6, it consists of two circular stout boards connected together with leather, in the form of a pair of strong bellows. A tube A communicates with the interior between the boards. Supposing the instrument to be strong enough, a person standing on the upper board may raise himself

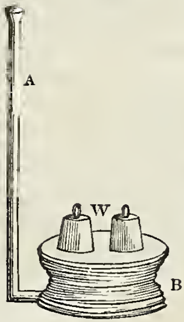

Fig. 6.

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22. How is the upward pressure of water shown?
23 How may the force of a small column of water be exemplified?

by pouring water into the tube, and filling it along with the bellows. It is usual to estimate the pressure by means of weights, W. If the tube hold an ounce of water, and has an area equal to a thousandth part of the area of the top of the bellows, one ounce of water in the tube will balance a thousand ounces placed in the bellows.

38. This remarkable property in liquids, which is called the *Hydrostatic paradox*, is analogous in principle to that which in mechanics is called the Law of Virtual Velocities.* According to this fundamental rule—a small weight descending a long way, in any given length of time, is equal in effect to a great weight descending a proportionally shorter way in the same space of time. The rule, as applied to liquids, may be stated thus:—A small quantity of water descending in a long column is equal in effect to a proportionately great pressure exerted by a large volume of water in a short column.

39. The law of pressure in proportion to height of column is shown in the annexed representation, Figure 7, of a vessel with an uniformly level base and full of water. Dividing the depth into 10 equal sections, to represent feet, as marked from 1 to 10, it is found, that, at the depth of 1, there is a pressure of one foot of water, at 2, two feet, and so on to 10 at the bottom, where there is a pressure of ten vertical feet of water. The average pressure of the whole is at the middle, at 5. These degrees of intensity of pressure have no reference to the horizontal breadth or length of the mass. The same pressure is sustained, whether the vessel be a foot or a mile in breadth.

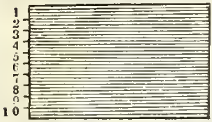

Fig. 7.

40. As in this example, whatever deficiency of pressure there is upon the perpendicular sides of a vessel of water *above* the middle or point of average pressure, is

* See MECHANICS, paragraph 16 to 27.

24. Describe the hydrostatic bellows, and its results.
25. Define the hydrostatic paradox.
26. Explain the diagram.

compensated by a corresponding excess of pressure *beneath* the middle; consequently, the entire pressure diffused over the sides is equal to that at the middle or point of average pressure. A perpendicular side of a cubical vessel, according to this statement, sustains a lateral pressure precisely equal to the half of that which is endured by the bottom.

41. We may calculate the degree of lateral pressure in vessels having perpendicular sides and flat horizontal bottoms, by first finding the number of square feet in the sides below the surface of the liquid; then multiplying that by the number of feet in half the depth of the liquid; by which calculation, the product will express the number of solid feet of the liquid, whose weight is equal to the lateral pressure. We may find the number of square feet in the sides, by multiplying the number of feet in the circumference of the bottom by the number of feet in the depth of the liquid.

42. Example.—To find the degree of pressure on the perpendicular sides of a vat 24 feet deep from the surface of the liquid, and 40 feet in circumference—Multiply the 24 by 40, and the product 960 gives the area of the sides; then multiply the 960 by half the height, that is 12, and the product is 11,520 cubic feet of water, or the volume of liquid whose weight is equal to the pressure on the sides. We next find the weight per cubic foot, which is reckoned to be 1000 ounces; then 11,520 multiplied by 1000, gives 11,520,000 ounces, which is the pressure of the water on the sides.

43. In consequence of the pressure of liquids being as the vertical height and area of the base, it may happen that the lateral pressure on the sides of a containing vessel is greater than the whole weight of the liquid; this will be the case when the surface of the sides in contact with the liquid exceeds the ratio of double the magnitude of the bottom—at double the magnitude, both lateral and perpendicular pressures are alike, and each is equal to the weight of the liquid.

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27. What of the lateral pressure?
28. How may it be calculated?
29. State the example and its result.

44. The circumstance of pressure increasing in proportion to depth, suggests the valuable practical lesson of greatly increasing the breadth of embankments for dams and canals from the top downwards, so as to give much greater strength to the base than the summit; also of increasing the strength of the lower hoops of large vats to prevent their bursting. It likewise demonstrates the propriety of making dams, ponds, canals, and vessels for liquids generally, as shallow as is consistent with convenience or their required purpose. In each case it is important to recollect that the degree of pressure on the sides is irrespective of shape or size of the contents, and depends exclusively on the height of the liquid from its upper surface to its base.

45. That pressure in water is not according to the volume, but the height above the point of pressure, is obvious from many facts both in nature and art. Whether we plunge an object a foot deep in the ocean or in a jar of water, the pressure upon it is the same. The mere extent of the volume of liquid is of no consequence. Therefore, a precipitous shore pressed upon by the sea to the height of any given number of feet, suffers no more pressure (supposing the sea to be at rest) than the side of a canal of the same number of feet in height.

46. If the law of pressure of fluids were otherwise than that now stated, no species of embankment, no strength of shore, could withstand the pressure of the ocean, particularly in a high state of the tide. In consequence of the law of pressure being simply as the vertical height, we are enabled by artificial means to stem the volume of a far-spreading ocean, and to secure the dry land from its invasion. A knowledge of this important law might induce the attempt to secure many thousands of acres of land which are now covered by the tide.

47. If a vessel, as for instance a barrel, be filled with water, and three apertures be made in its side at different

---

30. How may the lateral pressure exceed the whole weight?
31. What practical uses of this principle are named?
32. What facts in nature are referred to in proof?

heights, as in Figure 8, the liquid will pour out with an impetuosity corresponding to the depth of the aperture

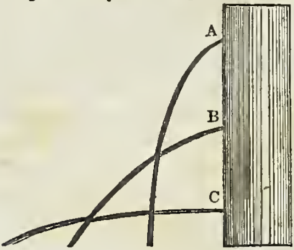

Fig. 8.

from the top. The jet A nearest the top of the barrel, having little pressure above it, will be projected but a short way; the jet B, having a greater pressure, will perhaps go to double the distance; and the jet C, having the greatest pressure of all, will go to a greater distance still. Jets of this kind obey the laws which govern solid projectiles in their flight;* they describe a curvilinear motion, the width of curve being proportioned to the impressed force.

48. Practically, the discharge of liquids from apertures is partly affected by the shape and width of the aperture; for water is retarded by friction, and by its own impetuosity or cross currents in a small channel.

49. It is reckoned that the pressure of water on any body plunged into it, or on the bottom or sides of the containing vessel, is about one pound on the square inch for every two feet of the depth.

50. Pieces of wood sunk to great depths in the ocean become so saturated with water by the pressure of the superincumbent mass, that they lose their buoyancy, and remain at rest at the bottom. The depth to which divers can descend is limited by the increased pressure they experience in their descent. If a bottle be firmly corked and sealed, and sunk to a great depth in the ocean, the cork will either be forced in or the bottle broken by the pressure. An air-bell rising from a depth, expands as it

* See Laws of Projectiles, paragraph 237, &c., Laws of Matter and Motion.

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33. Explain the diagram and the laws it exhibits.
34. How is water retarded, and what the ratio of pressure?
35. What examples of pressure are named?

approaches the surface. At the depth of a thousand fathoms, water is estimated to be about a twentieth part more dense in the bulk than at the surface.

51. The great effects that may take place by the action of a small but high column of water, are sometimes exemplified in the rending of mountains. In Figure 9, a mountain or high rocky knoll is represented, with a small vertical crevice A reaching from the summit to an internal reservoir of water near the base. If there be no means of outlet to the liquid, and if rain continue to keep the crevice and its terminating reservoir full, the lateral

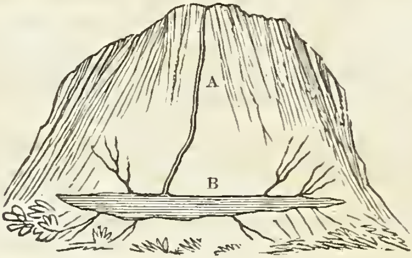

Fig. 9.

force exerted by the upright column will be very considerable. Supposing the crevice to be an inch in diameter, and two hundred feet deep, the pressure would be equal to nearly a half a ton on every square inch; such a force continually acting on the sides of the mountain (laying out of view the great additional force given by expansion of the liquid in freezing during winter) would probably in time overcome the cohesiveness of the mass, and burst the whole asunder. In this property in water, therefore, we see one of the many provisions of nature for producing changes on the surface of the earth.

52. Effects of a similar character. but on a less scale, are observable in the bursting of walls behind which earth

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36. Explain the diagram and its design.
37. What phenomena are thus explained?
38. What results from the mobility of the atoms of water?

has been piled, and in which no proper outlets for water have been provided; as also in the bursting upwards of drains upon a declivity, when they become choked.

HYDROSTATICS CONTINUED.

EQUAL LEVELNESS OF SURFACE.

53. On account of the perfect ease with which particles of water move over or among each other, a quantity or mass of them can have no solidity, firmness, or tenacity; accordingly, any such mass readily accommodates itself to the shape of any vessel or natural hollow in which it may be placed; the mass takes the form of the vessel or hollow, whatever it may be.

54. While the easy motion of the particles among each other causes them to accommodate themselves to the shape of any vessel, the force of gravity causes them at the same time, to seek the lowest level for repose. Each particle tries to get as low as it can. The result of this general tendency throughout the mass is a perfect levelness of surface; the top of the water is smooth.

55. AN UNIFORM LEVELNESS OF SURFACE takes place in every connected mass of water, whatever be its magnitude or its shape. This forms the third leading feature in the laws of water, and is the cause of many of the phenomena in nature.

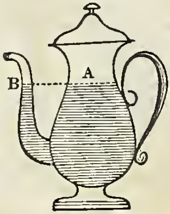

Fig. 10.

56. One of the most familiar examples of the equal height and levelness of surface of water is that observable in a common teapot. In the representation of a teapot, Figure 10, the surface of the liquid in the pot is seen to be at A, and also at the very same height at B in the spout. A straight dotted line is drawn from one to the other, to show that both surfaces are of the same level. It is customary to say that the small

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39. What is the third law of water and its result?
40. Explain the diagrams, Figs. 10 and 11.

column of water in the spout balances the large mass of water in the pot; but, in reality, there is no balancing in the case. The water necessarily possesses the same surface level in all its parts; one portion cannot stand higher than another; all portions, great and small, are only distributed parts of a single mass.

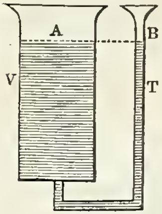

Fig. 11.

57. Figure 11 presents a similar example of the same phenomenon. V. is a vessel filled with water to the height of A. T is a tube proceeding first downward and then upward from the bottom of the vessel. In this tube, accordingly, the water stands at the same height or level at B as it does at A. There is nothing surprising in this, because it is only the same piece of water throughout.

58. Figure 12 represents a vessel formed of six different compartments, but all communicating with each other, and containing a body of water. As in the preceding instance, the water stands at a uniform level throughout, marked from A to B, notwithstanding the difference of shape of the compartments. Thus, it is of no consequence how we bend or twist the vessel into various shapes, for in every connected mass of water there must necessarily be but one uniform level.

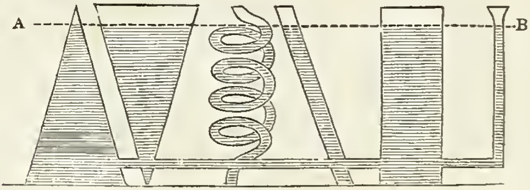

Fig. 12.

59. The tendency which water has to stand at the same surface level in all parts of its mass, is usually referred to by the phrase "water finding its level."

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41. What does Fig. 12 illustrate?

60. It is this inherent tendency in water to find its level that produces the various phenomena of the trickling down of rain and moisture into the ground, the flowing of all kinds of streams, from the small brook to the mighty river, and the shooting of rapids and cataracts over precipices. In each case, the water, in obedience to the natural law or tendency which governs it, is only trying to find its level. In pursuit of this object, the water, by the rubbing force which it exercises, wears down all the solid objects which present an obstacle to it in its course. Thus, the substances of which hills and plains are composed, are carried away by streams into the ocean—the ground of continents and islands diminishes in bulk—new land rises in the sea: and so, by the effects of a simple natural cause, great alterations are produced in the external features of the globe.

LEVELS.

1. There are two kinds of levels—the *true level* and the *natural level.**

62. The true level is a perfectly horizontal plane, as for instance an even line, thus ————————————, or a perfectly even surface of a floor.

63. The natural level is a surface, every point of which is at the same distance from the centre of the earth. The surface level of water is always the natural level.

64. The character of a natural level is understood by a reference to the spherical shape of the earth and the pressure of gravitation. The globe is a ball, and any piece of water which lies upon it, lies in the form of a plaster round the ball. Water, therefore, cannot possibly have a true surface level; its level partakes of the sphericity of the ball. Every piece of water, in a state of entire or partial repose, is in this manner convex in its surface.

65. The degree of convexity of the earth is, as nearly

* In mathematics, the term *apparent level* is used instead of true level, and the term *dead level* instead of natural level.

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42. What natural phenomena are thus explained?
43. How many kinds of levels are named?
44. Is the natural level of water convex, and why?

as it can be stated in figures, 7 inches and 9-10ths of an inch, or nearly 8 inches in each mile. The convexity, however, is somewhat less toward the north and south poles, because the earth is a spheroid, or a sphere flattened at the ends.

66. Figure 13 represents a segment of the earth's surface, with the appearance of a true and natural level marked upon it. The curve ES is the earth's surface. PC is a perpendicular line pointing to the centre of the earth. At right angles from this line, a line TL is drawn, representing the true level. Supposing that the line TL is a mile in length, if we draw a line from L to the centre at C, it will cut across the surface of the earth at a point a mile distant from the line at T, which point will be 7 inches and 9-10ths depressed below the part at L.

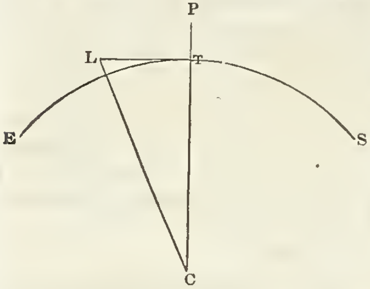

Fig. 13.

67. The convexity of the earth's surface is not observable in small quantities of water. The surface of a glass of water is not a true level, but the degree of convexity is so small that it cannot be practically estimated or measured. It is only when a sheet of water is stretched out to an extent of several miles, that the convexity becomes conspicuous. It is very perceptible on the ocean when a ship is seen approaching on the horizon; first the mast and sails of the ship are seen, and lastly the hull. In order to catch the first glimpse of vessels at sea, the point of outlook for them is placed high above the water. By this means, the person who looks is able to see over a part of the convexity, and give information of the approach of vessels to those placed below.

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45. What is the degree of convexity of the globe?
46. Explain the diagram.
47. How is the spherical level of the ocean seen?

68. The convexity of the land is not so conspicuous, in consequence of the many risings and fallings in the surface. It is only in some extensive alluvial plains in different parts of the world that the convexity can be perceived, in the same manner as at sea.

69. In forming roads, railways, and canals, it is necessary to make allowance for the convexity of the earth's surface. The first thing done in such cases is to survey the land by means of an instrument called a *theodolite*. One of the varieties of the theodolite is a small telescope fixed on a stand, and must, when looked through, be placed perfectly horizontal, or in a true level. To find a true level, an instrument is fixed below it, called a *spirit level*, and by that it is regulated.

70. A spirit level is in universal request in works of art requiring levelness of foundation or surface. It consists of a cylindrical glass tube, as in Figure 14, containing a quantity of spirits of wine sufficient to fill it, except a small part, in which the air is left. The tube being completely closed or sealed, the small vacancy where the air is left shows an air-bubble at whatever part of the tube is uppermost. The tube being set in a small wooden case with a level bottom, this case is laid upon the block of stone, wood, or other object to be levelled, and when the air-bubble is seen to rest in the middle of the upper side, it signifies that the object on which the instrument lies is a true level. In the accompanying figure, the air-bubble is seen at the middle at *b*; the slightest unevenness would cause the bubble to proceed to *a* at one end, or *c* at the other.

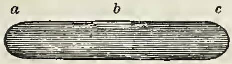

Fig. 14.

71. A true level being found for the theodolite, the surveyor looks through the glass or telescope towards a pole, the lower end of which rests on the ground, and is held in a perpendicular position by a man at (we shall suppose) the distance of a mile, previously measured. The pole having figures marked upon it, a certain figure on a level

48. By what instrument is the convexity of the land measured?
49. Explain the diagram, and the use of the spirit level.

with the eye is ascertained ; 7 inches and 9-10ths are then reckoned down the pole from the figure, and at that depth we have the natural level from which the surveyor makes his subsequent calculations. If a road were to be made on the plan of preserving a true level, it would proceed in its course at a tangent from the earth's convexity like the line TL in Figure 13, and, consequently, would reach a point above that to which it was destined to go. It would be impossible to make the water in a canal pursue a true level; in the attempt to do so, the water would not remain at rest in the channel prepared for it, but would rush towards the lower end.

72. As most countries are less or more irregular in surface, canals are usually constructed with different levels, so much of the length being on one level, and so much on another, as the case may be. At every change of level there is a lock, or portion enclosed with gateways, to keep the water at the proper level, and to allow the passage of vessels. The locks of a canal, therefore, are like steps of a stair, one at a greater height than another, and by their means vessels may be made to proceed up or down hill.

HYDROSTATICS CONTINUED.

SPECIFIC GRAVITY.

73. The more dense in substance that a body is, it is the more heavy or weighty, because it contains the more particles to be operated upon by attraction of gravitation. In reference to the density of bodies, the term *specific gravity* is employed to denote the comparison which is made. Thus, the weight of a lump of lead is greater than an equal bulk of cork ; therefore its specific gravity is greater ; and so on with all other substances, when compared together. For the sake of convenience, pure distilled water, at a temperature of 62 degrees, has been established as a standard by which to compare the specific gravity or

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50. Describe the use of a theodolite in canalling, &c.
51. By what means is the level changed in canals ?
52. What results are thus obtained ?

relative weight of solid and liquid bodies. Every such body is said to be of either a greater or less specific gravity than water, bulk for bulk.*

74. We have an example of a difference in the specific gravities of liquids, in mercury, water, oil, and spirits. Mercury is considerably more dense or heavy than any of the others; the next in density is water, then oil, and lastly spirits. If we put a quantity of each of these liquids into a glass vessel, one after the other, in the order here mentioned, we shall observe that all keep their respective places, without intermixture, the heaviest at the bottom and the lightest at the top. Should they even be jumbled together in the vessel, it will be noticed that they in time rectify the disturbance, each assuming its own position.

75. Sea or salt water, in consequence of being loaded with foreign matter, is of greater density or specific gravity than pure fresh water of the same temperature. If we therefore pour a quantity of salt water into a glass vessel, and then gently place some fresh water above it, we shall observe the same phenomenon, of each kind of liquid retaining its position, the heaviest to the bottom, and the lightest to the top. After being jumbled together, the two liquids will, as far as possible, return to their former relative position.

15.

76. If we fill a bottle with water, and dip it with the open mouth downwards into a jar or barrel of spirits, the water, in virtue of its density, will be emptied and sink into the spirits, and the spirits will immediately rush up into the empty bottle and supply the place of the water.

77. The force which liquids exert in opposing each other in a state of equilibrium, corresponds to their specific gravities; in other words, a small quantity of a heavy liquid will balance a much

* See paragraph 127 to 131, LAWS OF MATTER AND MOTION.

53. What of specific gravity, and what is the standard?
54. What variety in specific gravity may be shown?
55. What of salt and fresh water?
56. What experiment is cited?

greater quantity of a lighter liquid. For example, take a bent glass tube, as in Figure 15, and pour as much water into it as will extend from the bottom at E to A. This quantity of water will be balanced or kept to its summit level at A by a quantity of mercury measuring from E to B, or by a quantity of oil from E to C, or by a quantity of spirits from E to D. Each of these experiments may be performed one after the other. The pressure of liquids being as the vertical height, and not as breadth, it would make no difference in the result of the experiments, if the limb of the tube for the mercury, oil, or spirits, were increased to a foot, a mile, or any other diameter.

78. Water, at its ordinary temperature of 62 degrees, has a specific gravity of 1000 ounces to the cubit foot. Platinum is $22\frac{1}{2}$ times heavier, or $22\frac{1}{2}$ times the specific gravity of water; gold is $19\frac{1}{4}$, mercury $13\frac{1}{2}$, copper $8\frac{3}{4}$, iron 8, common stone about $2\frac{1}{2}$, and brick 2. Alcohol is a little more than 8-10ths of the heaviness or specific gravity of water, or 0·815; and oil of almonds is little more than 9-10ths, or 0·913. Atmospheric air at the earth's surface is 1-800th part, or 0·00125; in other words, while a cubic foot of water weighs 1000 ounces, a cubic foot of air weighs one ounce and a quarter.

79. Sea-water generally possesses a specific gravity of 1·035—that is, to 1000 parts of fresh water there are in addition 35 parts of saline substances.* Sea-water being, therefore, thirty-five parts for every 1000 of water more dense than fresh water, it possesses a proportionally greater power of buoying up bodies. A vessel which will carry 1000 tons on fresh water, will thus carry 1035 tons on the sea.

FLUID SUPPORT.

80. The immersion of solid bodies in liquids developes some important principles in hydrostatics.

* This is given only as a general rule. The sea is not uniformly salt.

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57. Explain the diagram.
58. Name the relative specific gravities of different bodies.

81. Any body of greater specific gravity than water, bulk for bulk, will sink on being thrown into water; but a body will float if its specific gravity be less than that of water.

82. The mode of stating the law in reference to the immersion and floating of solid bodies in any kind of fluids, is as follows:—

83. *First.*—Any solid body immersed in a fluid displaces exactly its own bulk of fluid, and the force with which the body is buoyed up is equal to the weight of the fluid which is displaced; therefore, the body will sink or swim, according as its own weight is greater or less than the bulk of displaced fluid. This refers to bodies of less density than water.

84. *Second.*—Any solid body of a greater density than water, when wholly immersed in that fluid, loses exactly as much of its weight as the weight of an equal bulk of the water—that is, of the water which it displaces.

85. It is of great importance that these propositions should be fully comprehended, for they explain innumerable phenomena in nature, in reference to the floating or swimming of bodies in water or in the atmosphere.

86. Water, as has been explained, consists of innumerable small particles, pressing in all directions, or upwards as well as downwards. Let us fix our attention on a supposed single particle in the mass; while the liquid is in a condition of repose, we may imagine the particle to be sustained between contending forces—the force of a column of particles above, and the equally strong force of particles beneath, pushing to get upward or away from this column.

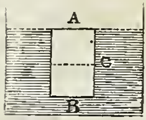

Fig. 16.

87. Let us now substitute any solid object for the supposed particle; for example, the quadrangular object AB represented in a vessel of water, Figure 16. This object, supposed to be of the same density as water,

59. Upon what does the floating of bodies depend?
60. What of bodies less dense than water?
61. And what of those of greater density than water?
62. Do these laws apply to all other fluids?

which we see is sunk in a buoyant condition in the water, has displaced a mass of particles, all of which were operated upon in the manner of the supposed single particle. This object, then, by taking the place of the mass of particles, has become subject to the same contending forces, and is consequently floated or sustained to the same extent as they were.

88. If we suppose that the weight of the object is two pounds, liquid to the amount of two pounds is displaced, and the object is pressed upwards with the force of two pounds. Or, to vary the example, suppose that only the lower half beneath the line C is the solid object, and that the space occupied by the upper half is water, the object is still pressed upwards with a force of two pounds; but being one pound weight in itself, and having a pound of water above it, it remains suspended in equilibrium.

89. These examples refer to bodies which are of the same density or weight as water, bulk for bulk: we shall now take an example of a body specifically lighter than water, by which it will be observed that the buoyancy is governed by the same principle.

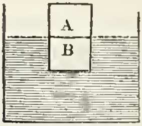

Fig. 17.

90. Figure 17 represents a solid object A B half immersed in a vessel of water. In this, as in all cases in which there is a portion of the object above the water, the weight of that portion is borne by, and therefore conveyed to, the portion which is immersed. Thus, in the example before us, the portion B, though less than a pound weight in itself, by supporting A, becomes, we shall say, a pound, and displaces a pound of water: it is therefore buoyed up with the corresponding force of a pound.

91. Whether a body be large or small in bulk, in proportion to its weight, its displacement of water depends exclusively on its weight, so long as it is not heavier than water. A vessel of cork, wood, or any substance lighter than water, weighing a thousand tons, displaces exactly

63. Explain the diagram and its purpose.
64. Explain the diagram and its principle.

the same weight of water, or is buoyed up with the same degree of force.

92. From these circumstances, it appears that the entire weight of any *floating* body may be calculated by measuring the quantity of water which it displaces.

93. On immersing a stone or any other solid object in water, it is found to be buoyed up in proportion as its specific gravity is less than that of water. If its specific gravity be greater than water, it will sink to the bottom, and if less, it will swim. As the water of the ocean becomes of greater specific gravity the greater the depth, it may happen that an object, which sinks at the top of the water, will remain suspended in equilibrium when it descends to a point at which the specific gravity of the water is equal to its own.

94. Whatever be the weight of any solid object when weighed in air, its apparent weight is lessened when weighed in water. Thus a stone may be moved with comparative ease in water, which cannot be lifted without considerable difficulty on land. The apparent diminution of weight in these cases is caused by the support afforded by the liquid. Attraction of gravitation, which is the cause of what we call weight, is counteracted more in water than in air, because the water has a tendency to buoy up the object. The weight of any object in water is thereby lessened to the extent of the weight of a bulk of liquid equal to the size of the object. If the object displace a pound of water, it will weigh a pound lighter in water than in air.

95. The circumstance of any solid object displacing its own bulk of liquid, and losing exactly as much of its weight as the weight of that bulk of liquid which it displaces, has led to the use of the hydrostatic or water balance for ascertaining the intrinsic value of gold and other precious metals. For example, by knowing in the first place how much water a pound of pure gold displaces, and then weighing in water, as in Figure 18, an object said to be a pound of gold, we should observe whether it displaced

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65. How may the weight of any floating body be measured?
66. What difference between water and air, and why?

the proper quantity of water; if it displaced more than was proper, then we should be certain that it contained alloy or some inferior substance, being too bulky for a pound of gold. Such weights are used by goldsmiths.*

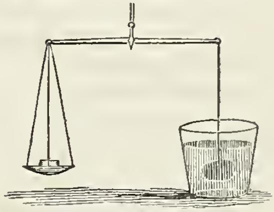

Fig. 18.

96. Thus, if a piece of gold weigh $19\frac{1}{3}$ ounces in air, it would weigh only $18\frac{1}{3}$ ounces in water; the ounce of weight thus counteracted being just the weight of the water that the gold displaces. Therefore the weight of the gold would be to that of the water as $19\frac{1}{3}$ ounces to 1 ounce; that is, the specific gravity of gold is $19\frac{1}{3}$, if water is taken for the standard.

97. We may cause an object, such as a light hollow ball, or bladder, to displace much more water than what is equal to its own weight; but in doing so, we must press the ball into the water, and that degree of pressure compensates the deficiency of weight in the ball. Thus, extraneous pressure on a floating body, and weight in the body itself, are the same thing as respects buoyancy.

98. The human body in a state of health, with the lungs full of air, is specifically lighter than water, and more so in the sea than in fresh-water. Persons, therefore, on going or falling into water, cannot possibly sink, unless they struggle so as to prevent the liquid from buoying them up. The body will float with a bulk of about half the head above the surface; and thus a person who cannot swim may live and breathe, until chilled or otherwise paralyzed, by simply stretching himself on his back, and with his face above the water. By throwing the arms out of the water, the body does not displace so

* See paragraph 132, LAWS OF MATTER AND MOTION.

67. Explain the nature and use of the hydrostatic balance.
68. What of gold as compared to water?
69. How is buoyancy affected by extraneous pressure?

much liquid; its weight is increased, and it naturally sinks. Ignorance of these facts in hydrostatics, and want of resolution, cause many deaths by drowning.

99. There are various kinds of apparatus for preventing drowning, called life-preservers. The most common are those which consist of pieces of cork or other very light material attached to the upper part of the body. But air-tight bags are preferable, as they may be said scarcely to encumber the body when empty, and, as danger approaches, they can be inflated with ease by being blown into. Life-boats have large quantities of cork in their structure, and also air-tight vessels made of thin metallic plates; so that, even when the boat is filled with water. a considerable portion of it still floats above the general surface. The bodies of some animals. as sea-fowl, and many other species of birds, are considerably lighter than water. The feathers with which they are covered add very much to their buoyancy. Quadrupeds swim much easier than men. because the natural motion of their legs in walking or running is that which best fits them for swimming. Fishes are enabled to change their specific gravity by means of an air-bag with which they are provided. When the air-bag is distended, they rise to the surface; when it is contracted, they descend to the bottom.*

100. The buoyant property of liquids is independent of their depth or expanse, for if there be only enough of

* The bodies of most fishes are nearly of the specific gravity of water, and, therefore, if living in it without making exertion, they neither sink nor swim. When this subject was less understood, many persons believed that fishes had no weight in water; and it is related as a joke at the expense of the philosophers, that a king having once proposed as a task to his men of science to explain this extraordinary fact, many profound disquisitions came forth, but not one of the competitors thought of trying what really was the fact. At last, a simple man [who doubted the fact] balanced a vessel of water in scales, and on putting a fish into it, showed a scale preponderating, just as much as if the fish had been weighed alone.—*Arnott's Elements of Physics.*

70. What useful lesson is given here?
71. What of life-preservers?
72. What animal peculiarities are named?

water to surround an object plunged into it, the object will float as effectually as if it had been immersed in a large mass of water. Thus, a few pounds of water may float an object which is a ton in weight. We account for these phenomena, by the law of pressure in liquids being as vertical height, not as width of column, and by a body being buoyed up with a force exactly in proportion to the weight of water which it displaces.

101. These important truths in hydrostatics teach the practical lesson that if canals be made only as deep or wide as will afford water to surround the vessels placed upon them, they will be sufficiently large for all purposes of buoyancy and navigation. A ship floats no better on the face of a sheet of water miles in width, than it would do on a mill-pond, provided there be enough of water in the pond to keep it off the bottom.

102. Every solid body possesses a *centre of gravity*, which is the point upon or about which the body balances itself, and remains in a state of rest, or equilibrium, in any position.

103. The equilibrium of floating bodies is regulated in the same manner. The floating body has a centre of gravity, about which the whole mass will balance itself in the liquid; the heaviest side will sink lowest, and the more light will be uppermost.

104. In reference to floating bodies, there is a point called the *centre of buoyancy ;* this is the centre of gravity of the liquid which is displaced. If the floating body be of the same specific gravity as water, the centre of buoyancy will be at the same point in the floating body as it would have been in the water; but there is seldom this uniformity, at least not in vessels used for purposes of navigation. It is necessary that all such vessels should be of a less specific gravity than water, in order that a part of their weight may be composed of cargo, stores, passengers, &c., and that they may be sufficiently buoyant.

105. Besides the centre of gravity and centre of buoy-

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73. By what law is the buoyancy of water calculated?
74. What practical hints are thus given?

ancy of a floating body, there is another important point called the *metacentre*, a word signifying *beyond the centre* This metacentre is a point in the *axis* of a floating body, the axis being a vertical line through the centre of gravity of the mass when it is at rest. In the case of a body floating at rest or perfectly stable, an ideal line uniting the centre of gravity and buoyancy is in a vertical position, as from B to G, Figure 19, and is called the line of support. W W is the water line. If the body is now inclined a little to one side, as in Figure 20, the direction of this line is no longer vertical, but slanting, as a line uniting B and G, (not shown in the cut.) If a line be supposed to pass upwards in a vertical direction from the centre of buoyancy B, it will meet the axis on a point marked M, which is the metacentre. Should the body sway in an opposite direction to the same extent, the point M will still be the metacentre. For different small inclinations from the position of equilibrium, the position of the metacentre is nearly the same; but for greater deviations, its position varies considerably.

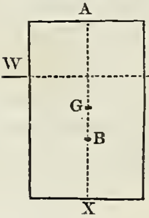

Fig. 19.

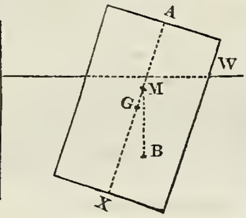

Fig. 20.

106. We have now to explain the practical use of a knowledge of these facts. When the metacentre happens to lie above the centre of gravity, as in the figure, the force of buoyancy acting upwards in the direction of the line B M, makes the body turn round its centre of gravity G, till it arrive at its position of rest, as in figure 19, after performing a few oscillations. But if the metacentre happen to lie below the centre of gravity, the buoyant force would turn the body in an opposite direction, and make

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75 Define the centre of gravity and of buoyancy.
76. What of vessels used in navigation?
77. Define the metacentre and explain the diagrams.
78. Of what practical use is this metacentre?

it depart still farther from its position of rest, till it would be upset.

107. The discovery of the centre of buoyancy and metacentre in any floating body, is a matter of mathematical investigation; the explanations here given, however, will show the nature of the calculations required in reference to the laws which secure the stability of floating bodies.

108. Heavy materials, called ballast, are usually placed in the bottom of the holds of vessels, to insure a low centre of gravity. A ship of the largest capacity and burden, with its centre of gravity properly regulated, rests in the water with a stateliness and stability which cannot be destroyed except by some extraordinary violence.

HYDROMETERS.

109. If a substance be weighed in two fluids, the weights which it loses in each are as the specific gravities of those fluids. Thus, a cubic inch of lead loses 253 grains when weighed in water, and only 209 grains when weighed in rectified spirit; therefore, a cubic inch of rectified spirit weighs 209 grains, an equal bulk of water weighing 253; and so the specific gravity of water is about a fourth greater than that of the spirit.

110. The instrument called a *hydrometer* is constructed upon this principle. Its name is derived from two Greek words, signifying *measure of water;* but it is of course used for ascertaining the density of all kinds of liquids. There are various kinds of hydrometers. One of them consists of a glass or copper ball with a stem, on which is marked a scale of equal parts or degrees. When immersed in any fluid, the stem sinks to a certain depth, which is indicated by the graduated scale. The length to which it sinks in the standard of comparison being known, we can thus easily ascertain how much it is specifically heavier or lighter than the fluid.

111. Much in the same manner is constructed another hydrometer of great delicacy and exactness. It consists

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79. What difference between weight in water and spirit?
80. How is the simplest form of hydrometer made?

of a ball of glass about three inches diameter, with another joined to it, and opening into it, of one inch diameter, *bc*, Figure 21, and a brass neck *d*, into which is screwed a wire *ae*, divided into inches and tenths of an inch, about ten inches long and one-fortieth of an inch in diameter. The whole weight of the instrument is 4000 grains when

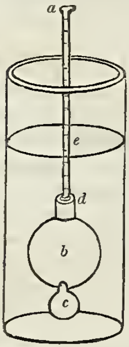

Fig. 21.

loaded with small weights, such as shot, in the lower ball *c*. When plunged into water in the jar, this instrument is found to sink an inch, if a single grain be laid upon the top *a*; hence a tenth of a grain sinks it a tenth of an inch. So great is the delicacy of this hydrometer, that the difference in specific gravity of one part in 40,000 can be detected. Its total weight of 4000 grains is convenient for comparing water; but the quantity of shot in the lower ball can be varied, so as to adapt the instrument to measure the specific gravities of fluids lighter or heavier than the standard of comparison.

112. There is another very simple hydrometer, which consists of a number of glass beads of different weights, but whose proportions are known, and the beads marked accordingly. These are dropped into the fluid under examination, until one is found which neither sinks to the bottom nor swims upon the surface, but remains at rest wherever it is placed in the liquid; and this bead being numbered, indicates the specific gravity.

113. In making calculations of the strength and specific gravity of spirits, by the above or any other means, attention must be paid to the degree of temperature of the liquid. Heat expands the liquor, and renders it specifically lighter; all spirits are therefore more bulky, in proportion to their weight, in summer than in winter, and also *apparently* stronger, not really so.*

* See paragraph 131, LAWS OF MATTER AND MOTION.

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81. Explain the diagram.
82. How does temperature vary specific gravity ?

HYDRAULICS.

Having detailed the laws and properties of water in a state of rest or equilibrium, we have now to mention some of the more important results of these laws, and also the effects which are produced upon liquids by the application of forces, whether natural or artificial.

WATER A MECHANICAL AGENT.

114. Water, as already explained in the LAWS OF MATTER AND MOTION, may be made a useful agent of power, merely by allowing it to act with the force of its own gravity, as in turning a mill; and in this manner it is extensively employed in all civilized countries possessing brooks which are sufficiently rapid in their descent.

115. But water may be rendered otherwise useful as an agent of force in the arts. Although subtile in substance, and eluding the grasp of those who desire to handle and hold it, it can, without alteration of temperature, be made to act as a *mechanical power*, as conveniently and usefully as if it were a solid substance, like iron, stone, or wood. The lever, the screw, the inclined plane, or any of the ordinary mechanical powers, are not more remarkable as instruments of force than water, a single gallon of which may be made to perform what cannot be accomplished (except at enormous cost and labour) by the strongest metal.

116. To render water serviceable as an instrument of force, it must be confined, and an attempt then made to compress it into less than its natural bulk. In making this attempt, the impressed force is freely communicated through the mass, and in the endeavour to avoid compression, the liquid will repel whatever movable object is presented to it. The force with which water may be squirted from a boy's syringe, gives but a feeble idea of the power of liquids when subjected in a state of confinement to the impression of external force.

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83. Define hydraulics.
84. What of water as a mechanical agent?
85. How is water rendered an instrument of force?

117. The mechanical force of water is exemplified by the hydraulic press. This is an engine employed by paper-makers, printers, and manufacturers of various kinds of goods, for the purpose of giving a high degree of pressure or smooth glazed finish to their respective articles. It has generally superseded the screw press, on account of its much greater power, with a less degree of trouble and risk of injury to the mechanism.

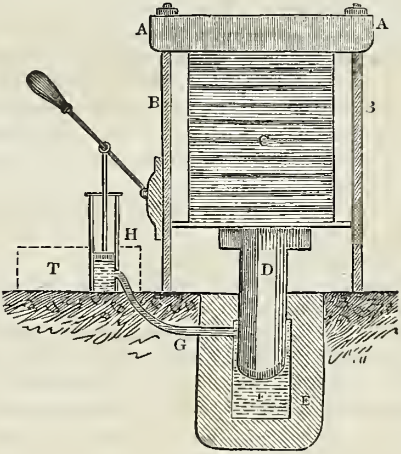

Fig. 22.

118. Figure 22 represents the outline of a hydraulic press. AB is the frame, consisting of four upright pillars supporting a cross top of great strength, and against which the pressure takes place in an upward direction. C, the material to be pressed, is forced upward by D, a round iron piston. This piston is very nicely fitted into an iron case E, which has a cavity F for receiving the water : the neck of the case grasps the piston so tightly that no water

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86. Describe the hydraulic press and its use.
87. Explain the diagram and its principles.

can escape. A small pipe G conveys water into the hollow cavity from a forcing pump H, which stands in a trough of water T. All that part of the apparatus below the base of the pillars is sunk out of sight in the ground. The pump apparatus is here represented as exceedingly simple, but in real machines it is very complex and of great power.

119. The pump, on being wrought, forces the water into the cavity. There the water, in endeavouring to escape, operates upon the moveable piston, which it causes slowly to rise with its burden. The pressure thus exerted by the liquid almost exceeds belief; unless the case for the water be of enormous strength, it will be rent in an instant as if made of the weakest material. When the weight has been raised to the required height, a stopcock is turned upon the pipe, and the apparatus remains at rest. The opening of the cock allows the water to gush out, and the weight accordingly sinks.*

120. The mode of calculating the power of the hydraulic press is analogous to that for calculating lever powers. Thus, the proportion is estimated between the small bore of the pump and the large bore of the cavity or barrel for the piston. Suppose that the pump has only one thousandth of the area of the barrel, and if a man by means of its lever handle, press its rod down with a force of five hundred pounds, the piston of the barrel will rise with a force of one thousand times five hundred pounds, or more than two hundred tons. A boy working the pump by a long handle, and taking a sufficiency of time, will raise a pressure of thousands of tons.

* The sheets of the present treatise are smoothed by being pressed between glazed boards in a hydraulic press. It is made entirely of iron, and wrought by two forcing pumps; by these a man is able by a quarter of an hour's labour to apply from three to four hundred tons of pressure. Each hydraulic press has a safety-valve to permit the escape of water when a certain pressure has been attained; unless there was a provision of this kind, no strength of metal could endure the pressure which might be applied. A good bydraulic press costs from £150 to £200.

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88. How is its power calculated?
89. How could the forcing pump be dispensed with?

121. In the hydraulic press, a force-pump is employed for the sake of convenience; the same end could be attained by a small column of water of a great elevation, on the principle of pressure in liquids being as vertical height.

AQUEDUCTS—FOUNTAINS.

122. The tendency in a liquid to find its level has permitted the construction of apparatus, consisting of pipes and cisterns, for supplying towns with water. No species of hydraulic machine has been of such great use to mankind as this apparatus.

123. In ancient times, the fact of water rising to an uniform level in every part of its volume, was either not perfectly understood, or there was a deficiency of materials wherewith to construct the apparatus required for carrying water a great distance.

124. From whatever cause, towns were in these times supplied with water by means of open canals, either cut in the level ground, or supported on the top of arches built for the purpose. These structures, with their elevated channels, were called aqueducts. In Italy, and some other countries in the south of Europe, the remains of stupendous aqueducts, miles in length, still exist.

125. By a knowledge of the laws of fluids, and by possessing an abundance of lead and iron, we are enabled in the present day to construct apparatus for supplying towns with water in a manner the most effectual and simple, causing a cheap iron or leaden tube, sunk in the ground, to perform the office of the most expensive and magnificent aqueduct.

126. The method of supplying towns with water consists in leading a pipe of sufficient diameter from a lake, river, or fountain of fresh and pure water, to the place where the supply is required. The iron pipes used for this purpose are composed of a number of short pieces soldered together,

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90. What of aqueducts and their value ?
91. How do the moderns possess superior advantages ?

and extending to any length or in any direction. From these main pipes smaller tubes of lead are led into the

Fig. 23.

houses requiring the supply of water; and by means of these minor tubes, the water may be carried to any point which is not of a higher level than the original fountain affording the supply.

127. Figure 23 is a representation of the mode of supplying towns with water in this convenient manner. A pipe is observed to proceed from a lake on the top of a hill down into a valley, and thence to supply a house situate on the opposite rising ground. From the pipe in its passage across the valley, a small tube is carried to supply an ornamental fountain or jet d'eau. The water spouts from this jet d'eau with a force corresponding to the height of the lake above.

128. In towns not commanding a supply of water from a sufficient height, the water is forced by an apparatus of pumps to an elevated reservoir, and from that the pipes are laid. When the water is impure, or loaded with muddy particles, it is usual to purify it by filtration at the reservoir; it is made to filter or ooze through a mass of fine sand, in which the particles of mud are deposited.

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92. Explain the diagram and its purposes.
93. How is a high level artificially obtained?
94. By what means may water be purified?

SPRINGS.

129. Springs in the ground are natural hydraulic operations, and are accounted for on principles connected with the laws of fluids.

130. One kind of springs is caused by capillary attraction, or natural attractive force by which liquids rise in small tubes, porous substances, or between flat bodies closely laid towards each other.*

131. This species of power is a remarkable variety of the mutual attraction of matter, and is as unaccountable as the attraction of gravitation, or the attraction exercised by the loadstone.

132. We may observe the action of capillary attraction in the case of two plates of glass brought almost in contact with each other, and placed with their lower end in a vessel of water. Figure 24 represents two glass plates placed in this manner in a vessel of water. The plates are somewhat separated at one side, and close at the other. We perceive, therefore, that the water has risen at the close side, and formed a curve in its upper surface from A to D, the degree of height of the liquid being in proportion to the closeness of the plates. The plates being more near each other at B than at C, the water stands higher accordingly at B.

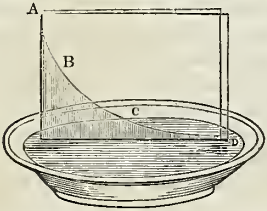

Fig. 24.

133. The rising of the water between these two plates of glass is precisely analogous to the rising of water from low situations in the earth through small fissures in rocks, or through porous beds of sand or clay, and so forming springs.

134. Springs from capillary attraction are believed to be less common and of smaller importance than springs which

* Laws of Matter and Motion, paragraph 41 to 45.

95. How are springs acounted for ?
96. Explain the diagram.

originate from the obvious cause of water finding its level. The water which falls in the form of rain sinks into the ground in high situations, and finds an outlet at a lower level, though perhaps at a considerable distance.

135. Some springs are also accounted for by a reference to atmospheric action, but these will form a subject of notice under the head PNEUMATICS.

HYDRAULICS CONTINUED.

FRICTION BETWEEN FLUIDS AND SOLIDS.

136. The flowing of water through pipes, or in natural channels, is liable to be materially affected by friction. Water flows smoothly, and with least retardation from friction, when the channel is perfectly smooth and straight. Every little inequality which is presented to the liquid, helps to retard it, and so likewise does every bend or angle in its path. A smooth leaden pipe will thus convey more water than a wooden pipe of the same capacity. Practically, an allowance is made in the magnitude of pipes for the loss of speed by friction. Where the length of the tube is considerable, and there are several bendings, it is not unusual to allow a third of the capacity for retardation.

137. By increasing the capacity of pipes, a prodigious gain is secured in the increase of water. The loss from friction on a small tube of an inch diameter of bore is so great, that one of twice the capacity will deliver five times as much water.

138. The rate at which water flows from an orifice in a reservoir, or containing vessel, is affected by the situation and the shape of the orifice.

139. The most favourable situation for the orifice is at the bottom of the vessel; but the velocity of the emission is not in the ratio of the height of the liquid, or of a perpendicular column of particles, and the water presses in all direc-

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97. What other sources of springs are named?
98. How is the flow of water retarded?
99. What proportion of gain by increasing the capacity?
100. How is the flow of water affected by the orifice?

tions alike; there is from all parts of the vessel a general rush as it were to the outlet, thus putting the whole mass in motion.

140. Although the rush of water at the outlet is not as the ratio of the depth, it depends upon the depth. Thus, if a vessel ten feet high be penetrated at the side on a level with the bottom, and the water stand at two feet and a half within, it will issue outwards with a certain degree of velocity. If the height of the water be quadrupled, that is, if the vessel be filled, the velocity will be doubled. In order to obtain a threefold velocity a ninefold depth is necessary, for a fourfold velocity sixteen times the depth is required, and so on. In fact, in whatever proportion the velocity of efflux is increased, the quantity of liquid discharged in a given time must be also increased in the same proportion; hence the quantity of water discharged conjointly with its degree of velocity will be increased in proportion to the pressure. There is here a striking coincidence between the descent of water and the relation which exists between the height from which a body falls, and the velocity acquired at the end of the fall.

141. It has been ascertained that water rushes with most advantage from an orifice, when the orifice is in the form of a short round tube inserted into the vessel, and of a length equal to twice its diameter.

142. It has also been found, that if the pipe, instead of being flush or level with the bottom of the reservoir, entered into it to some distance, it had the effect of making the flow of water even less than that which issued through the simple hole without any pipe. The singular fact of a pipe and hole of the same diameter discharging different quantities of water under different circumstances, whilst the head or pressure remains the same, must be accounted for by cross or opposing currents being created by the rush which all fluids make to the orifice. Currents will thus form from the top and sides of the containing vessel, and by

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101. How and what ratio may the velocity be varied ?
102. What of a short tube, and why the difference ?
103. What if the tube project into the interior ?

their inertia they will cross each other, and thus impede the descent of the perpendicular column, causing the water which issues to run in a screw-like form; this, however, is in a great measure obviated by the application of a short tube from the aperture. That the projection of the tube too far into the interior of the vessel should make the flow less than if there were no pipe at all, may be thus explained :— The columns which descend from near the outside of the vessel, by turning up again to reach the discharging orifice, come into more direct opposition to the motion of the central descending columns, whilst they are at the same time themselves compelled to turn suddenly in opposition to their own inertia before they can enter the pipe. Thus, the discharge is more effectually impeded than if it were proceeding from a mere opening in the bottom of the vessel.

143. The tube for the discharge of water should not only be short and round, but also trumpet-mouthed or funnel-shaped, both internally and externally, that being the form which admits the flow of liquid with the least possible retardation.

144. The effects of friction between liquids and solids are no where so conspicuous as in the flowing of rivers. The natural tendency in the water to descend at a certain speed, is limited by the roughness of the bottom, bends in the course of the stream, and small projections on the banks. From these causes, the water in a river flows with different velocities at different parts in any vertical section across the current. It flows at a slower rate of speed at and near the bottom than at the surface, and also slower at the sides than at the middle.

145. The resistance which a body moving in liquid meets with, when it comes in contact with a solid, is as the square of the velocity of the moving body; in other words, the resistance is not twice but four times with a double rate of speed. This is easily explained : —

146. A vessel moving at the rate of one mile per hour displaces a certain quantity of water, and with a certain

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104. What is the best form of the tube ?
105. What of the flowing of rivers ?
106. What relation between resistance and speed ?

velocity; if it move twice as fast, it of course displaces twice as many particles in the same time, and requires to be moved by twice the force on that account; but it also displaces every particle with a double velocity, and requires another doubling of the power on this account; the power thus twice doubled, becomes a power of four. When the body is moved with a speed of three or four, a force of nine or sixteen is wanted, and so on. Thus, the resistance increases as the square of the speed.

147. This important law suggests practical hints of considerable importance. For instance, in steam navigation, if an engine of fifty horse power impel a vessel at the rate of seven miles an hour, it would require two of the same power to drive her ten miles an hour, and three such to drive her twelve miles an hour. Hence the enormous expense of fuel attending the gaining of a high degree of velocity.

ACTION OF WATER IN RIVERS.

148. In cases where it is desirable to preserve the banks of rivers from injury, either from the regular action of the current or from floods, the water ought to be allowed a free open channel with banks of a very gradual descent. The utmost violence of water in a state of motion may be rendered comparatively harmless, by allowing the flood or torrent to expend itself on a sloping or shelving shore. Inattention to this simple fact in hydraulics frequently causes much destruction to property on the banks of rivers.

149. A very small fixed obstacle, such as a stone or pebble, may partially impede and turn aside a brook of a slow current. The water, by striking on a stone at one side, is bent aside to the opposite bank, a little farther down; there it strikes upon the bank, and is returned to the side it formerly struck. Thus, proceeding in currents from side to side, the banks become worn down at particular places, and, in time, a new and serpentine course is given to the stream. In the case of rivers flowing with

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107. How is this important in steam navigation?
108. What of the action of water in rivers?
109. What of straight and winding rivers?

considerable velocity, impediments of this kind are usually overcome, and the stream pursues its straight onward course, dashing down all obstacles to its progress. Thus, rivers are generally winding in their course in flat countries, and straight in mountainous regions.

150. It sometimes happens that the water at the surface of a river may be moving in one direction, while the water at the bottom is flowing in an opposite direction. This is an exceedingly interesting phenomenon, which is observed to occur in certain rivers communicating with the sea, and is caused by the action of the tides and the difference of specific gravity in salt and fresh water. When the tide is flowing inwards, the salt water rushes up the channel of the river, but not at such a depth as to stem the current of fresh water, which, being lighter, floats on the top of the salt water, and pursues its downward course to the ocean. In those instances in which there is no great disturbance of the two liquids, the fresh water, by its specific lightness, floats on the surface of the sea to a distance of many miles from the land.

WAVES.

151. Waves are the risings and fallings of the water, caused by some power, such as the blowing of the wind. The power, whatever it happen to be, communicates a force to the mass of liquid, and a series of undulations is the consequence.

152. These undulations, or waves, exhibit the transmission of the communicated force. The force does not advance or alter the lateral position of the water at any given point; it only alters the water in its vertical position, or in relation to its depth. When therefore waves advance, the water does not advance with them; the water but rises and falls, and assumes the figure of undulations on its surface. When the undulations approach the shore, the water then acquires a progressive motion, where it is shallow, and by friction on the bottom or impulsion against

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110. How are under currents explained?
111. What is peculiar in the undulations of waves?

the shore, the communicated force is exhausted. The shaking of a carpet affords an exact representation of the action of waves or undulations.

153. Waves are comparatively superficial; they seldom, even in the greatest storms, rise to a height of more than twelve feet above the level of calm water, and make an equal descent beneath, making altogether an appearance of twenty-four feet; at eight or ten feet below the hollow or trough of the waves the water is tranquil. Waves "mountains high" is only a figure of speech.

ALTERATION OF TEMPERATURE.

154. By altering the temperature of liquid bodies, they become liable to peculiar laws, and exhibit peculiar phenomena.

155. At a temperature of 40 degrees of Fahrenheit's thermometer, water is at the point of greatest density. When the temperature is reduced below this point, the liquid gradually increases in volume till it reaches 32, when it freezes. When the temperature is raised above 40, the volume increases till it reaches the boiling point, at which it has extended to the extent of 1–22d additional to its bulk.

156. In consequence of this expansibility in heating, hot or warm water is specifically lighter than cold water; therefore, in heating any mass of water in a vessel over a fire, the lighter or warmed particles rise to the top, while the cold and heavy particles sink to the bottom to be heated, and to rise in their turn. In this manner the process of heating proceeds, until all the particles are of an uniform temperature, which is at the boiling point, when the liquid gradually flies off in steam.

157. If water be heated by the action of fire, or the sun's rays on its upper surface, the mass is longer in attaining the vaporific point than when heated below, because water is a bad conductor of heat, and therefore the heat penetrates with difficulty through the upper stratum of warmed liquid to

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112. What of the height of waves?
113. How is the density of water in different temperatures?
114. What of gradually heating water over the fire?

reach that which is beneath; and if the mass be very large, as for instance the ocean, no intensity of heat applied above can warm it throughout, or to any considerable depth.

158. In the present treatise, our only consideration is the *motion* of the liquid while heating, or in consequence of the application of heat.

159. This motion consists in the rising of the heated portion of the water to the top, where it remains till cooled, when it is liable to be displaced from its position.

160. No mass of water can possibly be at rest, if of a higher temperature below than above, so long as the temperature exceeds 40 degrees. An upward and descending motion continues till the uniform temperature has been established, whatever be the size or shape of the containing vessel.

161. In consequence of the tendency in water to assume an uniform temperature in all parts of its volume, a plan has been devised for heating houses by means of a hot-water apparatus. A long winding iron pipe is carried from the top of a house to the bottom; there it passes through a fire, and thence rises to the top of the house again, where the two extremities may be made to meet in a small cistern or filler. In such a tube, water may be made to boil, or at least to attain a high temperature throughout its whole extent.

162. Figure 25 is a rude outline of a hot-water apparatus of this kind. P is the iron pipe, with the filer T at the top. F is the fire beneath, acting on the pipe. The projections R R give an idea of the winding of the pipe into rooms or passages. In the apparatus as usually erected, the pipes are of

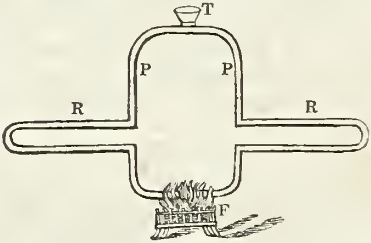

Figure 25.

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115. How is it when heated at its upper surface?
116. What of the motion of water by heat?
117. Explain the diagram and its principles.

about an inch in diameter, and are made to wind in all directions round the walls of rooms and passages, in their progress from the top to the bottom of the edifice. The degree of heat which is maintained in the water warms the atmosphere in the apartments, and obviates the use of fires.

163. Certain currents or sets of the ocean are known to be produced by the effort to attain an equability of temperature throughout. The power of the sun's rays at and near the equator heats the sea in that part of its volume, to the depth of two or three hundred feet. This upper stratum of heated water flows in currents towards the north and south poles, and there to a certain extent tempers the severity of the cold. The waters of the northern and southern tracts of ocean, displaced by these currents, necessarily sink below them, and push on towards the equator, to supply the deficiency caused by the departure of the waters above. Thus, in the economy of nature we see a process in constant action precisely the same in principle as that upon which the artificial hot-water apparatus has been established.

Having now discussed Hydrostatics and Hydraulics, we come to the kindred subject of Pneumatics, for which, as will be observed, we have reserved a notice of certain hydraulic machines involving pneumatical agency.

PNEUMATICS.

GENERAL DEFINITIONS.

164. Pneumatics, from the Greek word *Pneuma,* breath or air, is the name of the department of science which relates to the weight, pressure, or motion of air, or of any aëriform or gaseous fluids.

165. It was anciently supposed that the air of the atmosphere was an element or simple substance in nature. It is now satisfactorily established that air is not an elemen-

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118. How do the same principles act in nature?
119. Define Pneumatics.
120. Is air compounded, and of what elements?

tary body, but is composed of certain gases in intimate union, and these gases can be separated from each other by a process in art. The investigation of this subject belongs to CHEMISTRY.*

166. Air, in its common condition, is a thin transparent fluid, so subtile that it cannot be handled, and when at rest it cannot be felt.

167. That it is a body, however, is quite obvious, because we feel its impression or force when agitated as wind, or when we wave our hand quickly through it. In the quick motion of the hand, we feel that it is partially opposed by something; and in inhaling breath into the lungs, we feel that we are drawing something through the mouth—that *something* is air.

168. Air, like every other substance, whether solid or fluid, possesses a certain gravity or weight. The weight of air certainly, bulk for bulk, is much less than that of water; still the weight may be accurately computed. A bottle full of air weighs heavier in a balance than a bottle of the same capacity from which the air has been extracted.

169. A cubic foot of water, as has been mentioned (78),

* Pure air consists almost entirely of nitrogen and oxygen gases, with a very small portion of carbonic acid gas. Of 100 parts of air, reckoning by weight, 75.55 parts are nitrogen, 23.32 oxygen, and 1.13 carbonic acid and watery vapour. Both as respects weight and bulk, nitrogen forms the chief ingredient of the atmosphere. Air is rendered impure by fetid odours and other exhalations, which it has the power of holding to a certain extent. Animal respiration chemically changes the constitution of air; oxygen is destroyed or deposited in the blood, and carbonic acid is given out in its stead. Thus, we inhale pure air, and exhale that which is foul. As every full-grown person inhales about 400 cubic inches of air per minute, the tendency of respiration (not to speak of loss by combustion) to deteriorate the atmosphere may be easily conceived. Nature, however, abounds in provisions for preserving atmospheric purity. We need here only notice the beneficial effects of winds, the vast extent of ocean over whose surface is an inexhaustible reservoir of pure air, the purification by electric agency, and the influence of light or the solar rays. By whatever means effected, it is certain, from experiment, that the air now consists of the same ingredients, and in the same proportion, as it did fifty years ago.

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121. How is the material character of air proved?
122. How is the purification of air explained? (Note).
123. How is it proved that air has weight?
124. What relation does it bear to water in gravity?

weighs 1000 ounces. A cubic foot of air weighs only 523 grains, being a little more than one ounce; water, therefore, is about 840 times heavier than the air of our atmosphere.

170. Inasmuch as water is a standard for comparing the gravities of liquids, air is a standard in the same respect for all aërial substances.

171. The specific gravity of air being denominated 1000, oxygen gas is 1111; nitrogen gas 972; hydrogen gas 69; and carbonic acid gas 1529. The lightest of these kinds of gas, therefore, is hydrogen, and the heaviest carbonic acid. Hence if indefinite quantities of these aëriform bodies were placed in a vessel, or in an apartment, we should find, that, after certain portions had gone into intimate union, according to the laws by which they combine, the surplus portions of each would assume relative positions according to their respective weights—the heaviest to the bottom, and the lightest to the top. Such an experiment would resemble that previously noticed, of the mixture of mercury, oil, water, and spirits (74).

172. Air and all kinds of gases are rendered lighter by the application of heat, for then the particles in the mass are repelled from each other, and occupy a greater space; this process of lightening or thinning is called rarefaction. Rarefied air, being specifically lightest, mounts above that of a common density. The warmest air is always at the top of a room, and the coldest at the bottom.

173. Air is distinguished from water not only by its extreme comparative lightness, but the property of elasticity; it is a compressible and elastic fluid.

174. When any quantity of air is compressed into a smaller space than it naturally occupies, it will return to its natural bulk on the pressure being withdrawn.

175. A small bladder of air may be squeezed between the hands so as to be considerably reduced in size; and on opening the hands again, and withdrawing the pressure, it will instantly resume its former bulk. If a metallic tube or barrel be fitted with a moveable plug or piston, which is

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125. How is the specific gravity of gases computed?
126. What effect does heat produce on air?
127. What of the elasticity of air, with an example?

made to work in it perfectly air-tight, the air which occupies the space between the top and the bottom of this barrel when the piston enters, can be compressed to a hundredth part, or even less, of its usual bulk. If the force, however, by which the piston is pushed down, be withdrawn, the air, by its elasticity, will force it up again with a power equal to that by which its descent was resisted.

176. In proportion as any given volume of air is diminished by pressure, its elastic force is increased; in other words, the elastic force or elasticity of air is proportional to its density.

THE ATMOSPHERE.

177. The air, as formerly expressed, is a great ocean wrapped round the earth to a depth of from forty-five to fifty miles above the highest mountains, and forms a menstruum which is essential to the existence of all animals and plants.

178. This ocean of air penetrates into all unoccupied places, in the same manner as water flows into all crevices and holes beneath the level of its surface; and it also finds a place in the bodies of animals, plants, and liquid substances; hardly any thing, indeed, that we see in nature or art, is free from air, unless force has been employed to extract it.

179. The height of the atmosphere, though usually estimated at forty-five or fifty miles, is in reality unknown. The highest point above the level of the sea, which has ever been reached by any human being, is 21,000 feet, which has been attained in a balloon.

180. It is only conjectured, from the refraction of the sun's rays and other circumstances, that the height of the atmosphere is about fifty miles. At and near the level of the ocean it is most dense, in the same manner as water at the bottom of the sea is more dense than it is at the surface on account of the incumbent pressure. As we ascend

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128. How is the elasticity of gases computed?
129. What of the atmosphere and its importance and universality?
130. What of its height and density at different altitudes?

mountains, or in any other way penetrate upwards into the atmosphere, the air becomes gradually less dense, and so thin is it at the height of three miles on the summit of Mont Blanc, that breathing is there performed with some difficulty. Beyond this limited height, the density of the air continues to diminish, and at the elevation of about fifty miles, it is believed to terminate.

181. The extreme height of the atmosphere is not observable from the situation in which we are placed on the earth. Our eye, on being cast upwards, perceives only a vast expanded vault, tinted with a deep but delicate blue colour; and this in common language is called the sky. The blueness so apparent to our sense of sight is the action of the rays of light upon the thin fluid of the upper atmosphere, and the brightness is in proportion to the absence of clouds and other watery vapours.

182. In proportion as the spectator rises above the surface of the earth, and has less air above him, and that very rare, the blue tint gradually disappears, and if he could attain a height at which there is no air, say at above fifty miles in height, the sky would appear perfectly dark or black. Travellers who have ascended to great heights on lofty mountains, describe the appearance of the sky from these elevated stations as dark or of a blackish hue.*

183. The atmosphere possesses the capacity for absorbing and sustaining moisture, but only to a limited extent. When saturated to a certain degree, it is relieved by the falling of the moisture in the form of rain. It is calculated that the whole atmosphere round the globe could not retain at one time more moisture than would produce about six or seven inches of rain.

184. By an elevation of temperature, the capacity of the atmosphere to absorb and sustain moisture is increased, and by a lowering of temperature, decreased. Cold breezes, by lowering the temperature of the air, cause the aëriform moisture to assume the appearance of clouds, and then to

* See Treatise on OPTICS.

131. What of the blueness of the sky?
132. What of moisture and the capacity of the atmosphere?
133. How does temperature affect it?

fall as rain. Clouds disappear in fine weather, and again appear when it is cold. When a cloud descends on the side of a hill, it gradually enters a region of warmth or higher temperature, and disappears; but when a cloud ascends a hill, it enters a region of cold, and, consequently, being condensed, it is precipitated as a shower of rain. Hence the old familiar rhyme—

When the clouds go up the hill,
They'll send down water to turn a mill.

185. Thus, the atmosphere is the great field in which the varied phenomena of clouds, rainbows, meteors, and other appearances in the sky, are exhibited. As respects the phenomena of light itself, the atmosphere acts a most important part. Received in it, the rays of the sun are harmoniously diffused in all directions through it, as through a thick crystalline body, and afford light in situations which otherwise would be in darkness. The atmosphere, therefore, which an ignorant person might suppose to be *nothing*, is as invaluable a constituent of creation as land or water; it is a fluid essential for the existence of animals and plants; it affords a field for all kinds of meteorological phenomena; it is a supporter of combustion, and an important agent for the diffusion of heat and light, and also for the transmission of sound.

We shall now briefly enumerate the laws of aërial fluids, which it will be observed resemble those of liquid bodies.

PNEUMATICS—CONTINUED.

LAWS OF AIR.

186. *First*—The pressure of the air is equal in all directions: *Second*—Its degree of pressure depends on the vertical height or depth, and at any place is proportional to its density: *Third*—Its surface is level in all parts of its

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134. What phenomena are dependent on the atmosphere?
135. Name the laws of aërial fluids.

volume: *Fourth*—It affords support, according to its density and to the weight of the fluid displaced.

187. That air presses equally in all directions, may be rendered evident by filling a bladder with that fluid, and then pressing upon it so as almost to make it burst. The pressure is freely communicated through the mass, as in the case of the bag of water (21), and it will be observed that the confined air will rush out with equal impetuosity at whatever part you make a hole in the surface.

188. The level of surface of air is less perfect than the uniform level of water, on account of the greater elasticity of the substance. In a series of strata of air of different densities, one above the other, a small portion of each mingles with those which immediately adjoin it—the particles of one commingle to a certain extent with those of another. There is thus, as respects aërial bodies, a modification of the law of uniform levelness of surface in all parts of the volume of fluid.

PRESSURE OF AIR.

189. The pressure depending on the vertical height or depth of air, is an important property in the atmosphere, and on it depends the explanation of numerous phenomena.

190. Air being a substance possessing gravity, it must of necessity press downwards in the direction of the centre of the earth; and therefore the degree of pressure on any given point will be equal to the weight of the column of air above the point, and proportional to the density of the air at that point.

191. The idea of the atmosphere possessing the property of gravity or pressure, is of comparatively modern date. No such notion was entertained by the ancients, in consequence of living animals being observed to move with perfect ease in all directions, and because there was no other appearance in nature calculated to suggest it to their minds.

192. It was, however, remarked, that, when the air was

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136. What of the equal pressure of air, and its exact level?
137. How is atmospheric pressure computed and proved?

sucked out of a small glass tube, the lower end of which was immersed in water, the water rushed up into the tube and occupied the situation of the displaced air. In consequence of this and similar phenomena, it was alleged as a doctrine in physics, that "nature abhors a vacuum."

193. A vacuum is a space destitute of air or any other kind of matter; and the notion was, that whenever by any chance such an empty space was found, nature interposed with all imaginable haste to fill it. With this very rude idea, pumps were formed to raise water, the rising of the water in these instruments being ascribed simply to nature's abhorrence of a vacuum. At length it was discovered that water could not be drawn up by a pump above a height of about thirty-two feet, and that a vacuum above that elevation remained unfilled; whereupon the terms of the doctrine were changed, and it was said that nature abhorred a vacuum only to a height of thirty-two feet, but no farther.

194. This explanation was seemingly unphilosophical, and men's minds being carefully turned to the subject, various experiments were performed, and the important truth became manifest, that the atmosphere possessed gravity or pressure; also, that that pressure was the sole cause of the rushing of liquids into tubes exhausted of air—the height of the ascending liquids being in every case limited by the degree of pressure of the incumbent atmosphere. Thus, the discovery of a simple truth in science at once abolished the fantastic doctrine of nature's abhorrence of a vacuum, and all the laboured sophistry with which it was supported.* Nature has no dislike to a vacuum; a vacuum will occur in all situations from which solids or fluids are accidentally or artificially excluded.

195. The degree of pressure imposed by the atmosphere on any given spot on the earth's surface, as already noticed (190), is equal to the weight of the column of air above

* This great discovery in physical science was made by Torricelli, an eminent Italian mathematician, about the year 1644. It was suggested by an ineffectual attempt to raise water from a deep well near Florence, by means of a pump of a greater height than thirty-two feet.

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138. What of the maxim, "nature abhors a vacuum?"
139. How did Torricelli discover atmospheric pressure?

that spot, and is also proportional to the density of the air at the place. The atmosphere is deepest or of greatest vertical height at the level of the ocean, and there it exerts the greatest pressure. The pressure of the air at the level of the sea is usually reckoned to be about 15 pounds on every square inch.*

196. The pressure of 15 lbs. to the square inch refers to every shape of surface at or near the sea's level. The pressure is sidewise, upward, oblique, and in every other direction, as well as downward, because fluids press equally in all directions. Thus, in every crevice, nook, or vessel, in which air happens to be, the pressure is equally intense. The human being, for example, sustains the pressure of 15 lbs. to the square inch all over his person, and this is a load under which he could not possibly move,† unless the pressure was also exerted in the interior of his body, or through his whole system of muscles, viscera, and bones, by which means the external pressure is counteracted, and he feels no pressure whatever.


Figure 26.

197. If, however, the air by any means be withdrawn from the interior of any object that object becomes immediately susceptible of the external atmospheric pressure. There are many familiar examples of this pressure around us. One of the most common consists in causing a thimble to adhere to the hand by sucking the air from beneath it: the adhesion is the result of the pressure of the atmosphere on the exhausted space on the hand. Another consists in lifting a stone by means of a sucker, formed of a string and a wetted piece of leather, as in the accompa-

* The actual pressure varies from 14 lbs. to 15 lbs., according to circumstances. By various authorities it is stated at 14.7 lbs. For convenience, we state it throughout in the text at 15 lbs.

† The body of a man has a surface of 2000 square inches, and therefore the pressure upon him is equal to 30,000 lbs.

140. What of the degree of this pressure and where the greatest?
141. How much to the square inch?
142. In what directions is the pressure exerted?
143. Why do we not feel this enormous pressure?
144. Explain the diagram.

nying figure. The wetted leather is in this case pressed down upon the stone, and the string is then pulled: if air were admitted under the end of the string, the sucker would come off; but none being admitted, the atmosphere presses on the sucker, a rigid adhesion of the sucker to the stone is produced, and the stone, if not too heavy, is lifted.

198. The surgical process of cupping is upon the same principle. A small glass cup is held with its mouth near the part to be operated on, and the air being consumed within it by a lighted taper, it is instantly applied, and adheres with great force. The part having been previously lanced, the blood, rushing to fill the vacuum, enters the cup in copious small streams. The feeling endured in cupping is that of considerable weight.

199. The feet of flies and some other insects are formed on the principle of the sucker, by which means they are enabled to walk and run with security on the ceiling of an apartment, back downwards, or on an upright and smooth pane of glass. At each step in advance, they procure a hold by the formation of a vacuum or air-tight space beneath their feet. The rapidity with which these vacuums or air-tightnesses are formed and destroyed is an exceedingly interesting phenomenon in the economy of the animal, and cannot be rivalled by the utmost efforts of human skill. On a very moderate computation, a fly, in travelling six feet in the space of a minute, creates and destroys as many as 10,000 vacuums. When deprived of the outer extremities of its legs, on which the apparatus for adhesion is situated, a fly can walk without any apparent difficulty on a horizontal surface, such as a table, but is quite incapable of adhering to the roof, or of climbing any upright surface.

200. Limpets, snails, and some other crustaceous animals, adhere to rocks and stones, by causing a vacuum within their shells, which they accomplish by shrinking into a smaller hulk; by this simple contrivance, nature has effectually provided for their safe adhesion to their appropriate places of residence.

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145. What other examples are cited?
146. What of flies walking on the ceiling?
147. How is a vacuum formed by certain animals?

THE AIR-PUMP.

201. Air may be artificially withdrawn from a containing vessel by means of an apparatus called the air-pump. This apparatus is usually small, for standing on a table, and consists chiefly of a glass jar called a receiver, placed mouth downwards over a flat surface, and with a small brass pump to draw the air from it. The annexed cut, Figure 27, represents an outline section of an air-pump, the working of which may be described. R is the glass receiver standing on a flat and smooth plate SS, and fitting so exactly that no air can penetrate between the edges of the receiver and the plate. In the plate SS, there is a channel AB issuing into the barrel of a pump. P is the piston of the pump, with its rod C above, which is moved upwards and downwards by a handle and winch. The rod C works in a tight collar D. At the bottom of the pump there is a valve V, by which the air is to escape, and prevented from again entering. On depressing the piston, a portion of the contained air is expelled by the valve, and on raising the piston again to its position at the top, another column of air is admitted from the receiver into the pump, which is expelled in its turn. Thus, by a process of expulsion, the air in the receiver becomes at every stroke downwards more rare, till at length a vacuum sufficient for all practical purposes is established. The valve V, which opens outwards, is kept forcibly shut at every rising of the piston by external pressure of the atmosphere.

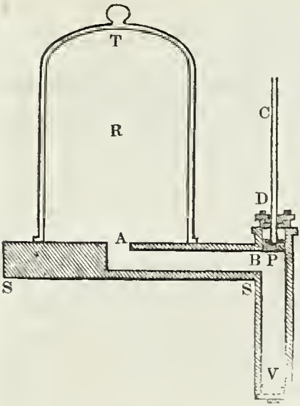

Figure 27.

148. Describe an air-pump, and its use.
149. What experiments are cited ?

202. By means of the air-pump, a number of interesting experiments in pneumatics may be performed. For example, if a bladder, half full of air, and tightly tied at the neck, be placed under the receiver, and a vacuum then produced, the air in the bladder will expand by the removal of the external pressure, and seem as if ready to burst. Dried raisins, during a similar operation, will expand, and have all the plumpness of new fruit; and an egg, by the expansion of its confined air, will explode. Any small animals, such as mice, placed below the receiver, and deprived of air, will immediately die, both from want of breath and the expansion of their bodies.

203. The atmosphere serves to retard the falling of bodies of a light and porous nature, and, therefore, in the exhausted receiver of an air-pump, all such bodies descend with the same velocity as bodies of a heavy compact nature. A piece of coin and a feather let fall at the same instant of time, from a hook within the top of an exhausted receiver, will strike the bottom at the same moment.*

204. That atmospheric air is useful for the transmission of sound, in the absence of other media, is also exemplified by the air-pump. If we place a small bell in a receiver in such a manner as to admit of being rung easily from the outside, without admitting air into the inside, whilst the receiver is full of air the sound of the bell will be distinctly heard; but after the receiver has been exhausted, and although the bell be struck with the same force, the sound will be inaudible, or nearly so. If a small portion of air be admitted, it will be faintly heard, and it will gradually increase, according to the quantity of air which is allowed to enter the receiver. Thus, we are indebted to the air as a medium for conveying to us the sound of each other's voices, and all the melodious notes which constitute music.

205. The act of inspiring and expiring air resembles the alternating action of an air-pump. The air, on being drawn in through the appropriate tubes, fills the lungs, and the

* LAWS OF MATTER AND MOTION, paragraphs 173, 174, 175.

150. How is air shown to be necessary for transmitting sound?
151. What animal function resembles the air-pump?

chest is expanded; having performed its office, the air is expelled in an impure condition, leaving a partial vacuum within, until another inspiration causes another expansion.

206. A machine, called a condensing pump or syringe, is formed for the purpose of showing experiments with air more dense than that of the common atmosphere. The apparatus, which is represented in Figure 28, consists of a close glass jar or receiver fixed in a frame. A wire and hook serve to communicate with the interior during the performance of experiments. The syringe *i* is wrought by a piston with the handle *k*. From the bottom of the syringe there is a tube communicating with the interior of the receiver. When the piston is raised, a valve beneath opening inwards admits air into the cylinder of the syringe, and when it is depressed, this quantity of air is forced into the receiver; by the alternate raising and depressing of the piston, an immense quantity of air is forced into the receiver.

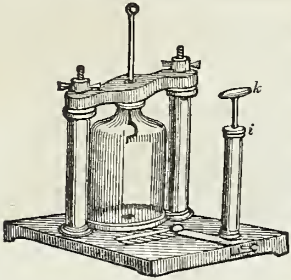

Figure 28.

207. The elastic force of air so condensed is very great, and is employed for the projection of balls from an instrument called an air-gun. A certain quantity of compressed air is confined in a chamber at the inner end of the barrel, and when allowed to escape by touching a valve, a bullet is projected with a force resembling that by gunpowder.

208. The explosive force of gunpowder itself is nothing else than the sudden disengagement of air from the particles of the powder.

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152. Explain the diagram.
153. What of an air-gun, and of gunpowder itself?

PNEUMATICS CONTINUED.

PRESSURE OF AIR ON SOLIDS AND LIQUIDS.

209. The pressure of the atmosphere affects all liquid as well as solid bodies. The load of the incumbent air is as sensibly exerted *within* any given mass of water as on the surface. Thus, atmospheric pressure keeps water and other liquids at the density they are usually seen to possess.

210. If a glass be filled with water, and placed under the receiver of an air-pump, the abstraction of the air, by the removal of the atmospheric pressure, will cause the water to expand or become less dense, and it will overflow the vessel in which it is contained.

211. Water in its ordinary condition contains a certain quantity of particles of air mixed up with it. When the atmospheric pressure is lightened, these particles of air expand, and being of a less specific gravity than water, they mount to the top of the liquid in the form of small globules, and so fly off. The same effect is produced by expanding water by means of heat; the globules of air rise to the surface, and escape or remain attached to the inside of the vessel. Crystal bottles of water may be observed to be covered inside with small air-bells when the weather becomes suddenly light or warm. Water which has been boiled is comparatively free of air, and has an insipid flavour.

212. Certain gases are generated in some liquors, such as in porter, beer, and champagne wine, and unless the bottles in which they are contained be of sufficient strength to endure the expansive tendency, they will burst. On drawing the cork from a bottle of one of these liquors, the confined gas or air is suffered to expand, and the contents gush forth, a mixture of froth and liquid. If the liquid remain in an open glass for a short time, a large portion of

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154. How is air shown to exert pressure within liquids?
155. What proofs have we that water contains air?
156. What of gases generated in certain liquors?

the long-confined gases escapes into the atmosphere, and the liquor seems flat or dead. A portion of confined air, however, still remains in consequence of the atmospheric pressure. If we take a glass of ginger-beer which seems quite dead, and place it under the exhausted receiver of an air-pump, it will again froth and appear brisk.

213. Some mineral waters on springing from the ground sparkle like beer. These most likely rise from great depths, where the incumbent pressure is considerable, and on attaining the surface of the earth they expand, and give forth the air pent up in their mass.

214. If a bladder full of air be carried from a low situation to a great height, the contained air will expand, and the bladder will burst, the same as if placed under the exhausted receiver of an air-pump.

215. If a bladder be filled with air at a great height, where the fluid is rare, and brought to a low situation, the contained air will be compressed by the more dense fluid without, and the bladder will appear as if only half or partially filled.

216. The fluids in the animal and vegetable system are similarly affected by atmospheric pressure. Our bodies, for instance, would expand, and our blood-vessels probably be ruptured, if placed for a short time in a vacuum. On the same principle, any change in the density of the atmosphere has an effect on the animal frame.

217. The atmospheric pressure, in ordinary conditions of the air, and at the level of the sea, as already stated, is equal to 15 lbs. to the square inch. If by any means, such as digging into the earth, we should go below the sea's level, the weight will be found to increase. In deep coal mines, for instance, the pressure of the atmosphere is something more than 15 lbs. to the square inch.

218. The pressure diminishes in a similar degree as we ascend into the atmosphere. At every step upwards from the shore, the burden of the superincumbent mass lightens.

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157. What of mineral waters?
158. How of the experiments with a bladder?
159. How are the fluids of the body affected?
160. How may the pressure be increased, or diminished?

At the height of three miles, one-half of the weight is lost; or in other words, at that height the air is only half the density of air at the sea's level.

219. The breathing apparatus of animals is suited to an atmospheric density and pressure such as is found at the sea's level, or at a moderate elevation above it. By ascending in the atmosphere, as in climbing hills, we are deprived of the quantity of air to which we have been accustomed; and when we reach a height of three miles, we in reality inhale only one-half of the weight of air into the lungs that we use at the sea's level. Consequently, those who ascend to great elevations experience difficulty in breathing, and feel an expansion in their blood-vessels and muscles by the removal of a portion of the ordinary pressure.* All the joints in our bodies, particularly those of the knee and shoulder, are in a great measure held together by the external pressure of the atmosphere; and thus a principle in Pneumatics compensates for a loading of muscular ligaments.

220. A consideration of the effects of atmospheric pressure, and its variability at different elevations, also the alterations in pressure caused by the expansion or lightening of the air by heat, and its increased density by cold and moisture, tends to explain the remarkable influence which change of climate has upon the human constitution. Thus, the inhabitants of countries possessing a light dry atmosphere are usually more lively than those of countries with a heavy moist climate.

PRESSURE ON MERCURY—THE BAROMETER.

221. The pressure of the atmospheric column, at any given point, may be weighed with considerable exactness,

* It is known that travellers, and even their practised guides, often fall down suddenly as if struck by lightning, when approaching lofty summits, on account chiefly of the thinness of the air which they are breathing, and some minutes elapse before they recover. In the elevated plains of South America, the inhabitants have larger chests than the inhabitants of the lower regions—another admirable instance of the animal frame adapting itself to the circumstances in which it is placed. —*Arnott's Physics.*

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161. How are animals affected by atmospheric pressure?
162. What of the effects of a change of climate?

by balancing it against an opposite column of mercury, water, or other liquid.

222. The pressure of 15 lbs. to the square inch at the ocean's level is found by experiment to be equal to the weight of a column of mercury of 30 inches in height, a column of water 33 feet in height, or a column of oil 37 feet in height. In other words, the burden of the whole of our atmosphere is equivalent to an ocean of mercury covering the earth to a height of 30 inches, an ocean of water to a height of 33 feet, or an ocean of oil to a height of 37 feet.

Fig. 29.

223. The fact of such being the degree of atmospheric pressure admits of easy proof, by means of a glass tube upwards of thirty-two inches in length, and a cup half filled with mercury, as represented in Figure 29. The tube is close at its upper end at B, but open at its lower extremity, which is immersed in the mercury below the surface level C P D. The tube having in the first place been filled with pure mercury, a finger is placed on its open end to prevent the egress of the liquid, and thus held, the lower end of the tube is turned downwards, and plunged into the vessel of mercury, when the finger is removed from the orifice. The mercury in the tube will now be observed to fall to E, or the height of about thirty inches above the surface CPD, and there it will remain.

224. The question now arises, Why the mercury in the tube does not run out altogether into the cup, instead of standing to a height of thirty inches in the tube? The explanation of the phenomenon is, that from E to B in the tube is a vacuum, and therefore the mercury at its upper extremity is entirely free of atmospheric pressure—there is no superincumbent weight to push it out. The column of mercury EP presses with nothing but its

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163. How may the atmospheric pressure be weighed?
164. What calculations are stated?
165. Explain the diagram and its design.

own weight on the mercury of the cup. This weight of thirty inches of mercury is counterbalanced by the pressure of air on the surface of the mercury in the cup; and thus it is evident that the weight of the atmosphere is equivalent to the weight of thirty inches of mercury. If by any means we remove the atmospheric pressure from the mercury in the cup, the mercury in the tube will immediately sink into the cup.

225. The circumstance of the column of mercury in the tube being narrow, and the surface of the mercury in the cup being broad, makes no difference in the experiment, because the pressure of elastic fluids is as their density, not as width of volume. The same result would occur if the surface of the mercury presented to the atmospheric pressure were only the width of the tube.

226. The height at which mercury stands in a tube of this kind, always bears reference to the incumbent weight of the atmosphere on the open and lower extremity of the column. If we increase the external pressure by artificial means, or by descending below the sea's level, the mercury rises; if we decrease it by artificial means, or by ascending into the atmosphere, or if the atmosphere is rarefied by heat, the mercury falls.

227. This very obvious connection between the rising and falling of mercury in a tube, and the atmosphere, has suggested the construction of an instrument called the *Barometer* (a word from the Greek, signifying *weight* and *measure*), by which the effects of atmospheric pressure may be accurately known.

228. The barometer in common use consists of a narrow glass tube upwards of thirty inches in length, and bent upwards at its lower extremity, as represented in Figure 30. The mercury is introduced into the tube with great care, so that a perfect vacuum exists at the upper extremity. The surface of the mercury in the bent part is open to the action of the atmosphere, and buoys up a small plummet or float F, to which a thread is attached; the thread proceeds upwards to a small pulley G, over which

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166. What instrument has been constructed on this principle ?

it goes, and terminates in a small ball W. The friction of the thread on the pulley turns a small index H, which points to figures on the surrounding dial. Commonly, the whole apparatus, except the dial plate, is concealed in an ornamental frame.

Figure 30.

229. Barometers of this description are adjusted in such a manner that the smallest rising or falling of the mercury from atmospheric action, affects the index on the dial, and shows the degree of pressure.

230. In common circumstances, the mercury ranges from 29 to 30 inches. It seldom sinks so low as 28 or rises to 31. When it falls, an indication is given of diminished pressure, and as diminished pressure causes the air to expand, and consequently to be sensibly cooled, moisture is liable to be precipitated in the form of rain (184). Hence a fall in the mercury of the barometer is considered a prognostic of rain or wet weather, and a rise the reverse. The dial of the barometer is marked accordingly.

231. The barometer, besides being a weather-glass, is used as an instrument for measuring the heights of mountains, or heights attained in balloons, above the level of the sea.

232. As the entire atmosphere sustains thirty inches of mercury in the tube, it follows that at every step as we ascend, the pressure will become less, and a less body of mercury be sustained. It is found that at the height of five hundred feet the mercury has sunk half an inch. But the fall does not proceed in this ratio as we go upwards, because a half of the whole atmosphere is within about three miles, and the other half expanded to an altitude of about fifty miles. Hence, on gaining a height of three miles, the mercury is found to have sunk to fifteen inches,

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167. Explain the diagram.
168. What are the indications of this instrument?
169. To what other uses is it adapted?
170. What of ascending to a great altitude?

or one half, and on gaining a height of four miles, to twelve inches.

233. Barometers for measuring heights are constructed with a determined scale, marked along the tube of mercury, and by consulting it as we ascend, we learn the height of any spot that we may reach. Perfect exactness, however, is not to be expected in this mode of measurement, because the atmospheric pressure is liable to variation from temperature, and the mercury is liable to contraction or expansion from the same cause. To guard against error, a thermometer, as well as a barometer, is consulted in ascending heights, and the indications of both instruments according to a scale established by experiment, determine the degree of elevation. Thus, for a diminution of one degree of temperature between 0 and 32 degrees, the mercury in the barometer falls 0.0034 of an inch, and between 32 degrees and 52 degrees it rises 0.0033 of an inch.

PRESSURE ON WATER—PUMPS.

234. The effect of atmospheric pressure on water is observable in various contrivances in the arts.

235. Fill a glass to the brim with water, and lay a piece of paper over the whole surface of the liquid; then turn the glass carefully upside down, holding on the paper by the hand; the water will now remain in the glass, being upheld by the pressure of the atmosphere against the paper.

236. Glass fountains of water for bird-cages, ink-holders, and reservoirs of oil for lamps, are constructed on the principle of the liquid being upheld by atmospheric pressure.

237. The apparatus for lifting water from wells, forming the common sucking-pump, acts on the principle of removing the atmospheric pressure from a column of the liquid, thus causing a vacuum in the pump, and allowing the atmospheric pressure on the surface of the liquid in the well to force up and balance the column of liquid.

238. Figure 31 represents the outline of a common

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171. How may perfect exactness be attained?
172. What examples of atmospheric pressure?

sucking-pump. It consists of a cylinder, furnished with a piston A made to fit air-tight. In this piston there is a valve opening upwards, not seen in the cut. When the piston is raised, the air is rarefied more and more at each stroke in that portion of the cylinder through which it has moved upwards, and the pressure of the air upon the surface of the water on the outside of the tube forces the fluid into it. The valve B is at the same time opened upwards, and the water after several strokes rushes in above it. When the upward stroke of the piston is complete, it is again depressed, the water passes through the valve in the piston; and on the next stroke, it is discharged at the spout. It is evident, that, when the piston is sunk downwards, the water cannot be again forced out of the pump, because the valve at the bottom is pressed down, and prevents its escape.

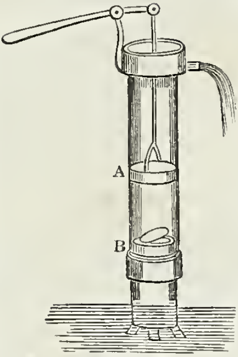

Figure 31.

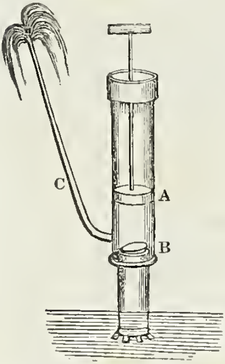

Figure 32.

239. Water may in this manner be lifted by a pump to any height, but in each case the lower or fixed valve in the pump must be less than 34 feet from the surface of the water. It is, however, disadvantageous to lift water from great depths by this means. In such cases, therefore, it is usual to employ a succession of pumps one above another.

240. It is customary to call pumps hydraulic machines; properly speaking, they are both

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173. Explain the first diagram.
174. Are pumps merely hydraulic machines?
175. What of the forcing pump, and its uses?

hydraulic and pneumatic machines, for water is raised by them in a great measure through the agency of atmospheric pressure.

241. The form of pump used for forcing water to a height above the ground, as in the case of fire-engines or portable forcing-pumps for gardens, is different from the common suction-pump. The object in the forcing-pump is to lift water to a certain height by the formation of a vacuum, and then to inject it with violence into the air.

242. The action of the forcing-pump apparatus is represented in Figure 32. The piston A sucks the water by its upward motion; but on depressing it, the valve B is closed, and the water is consequently forced through the pipe C.

243. In the case of supplying water to the boiler of a steam-engine, it is necessary to employ a forcing-pump, in order to overcome the pressure of steam within the boiler. The force with which the water is injected overcomes the tendency which the steam has to rush out.

244. Cold or moderately warm water can only be lifted by a pump. If the water be above a certain temperature, about 150 degrees at the utmost, the sucker cannot form a perfect vacuum, because, in the attempt to do so, the water yields a steam or vapour which fills the space; in other words, by removing the atmospheric pressure by the piston, the water begins to vaporize as if about to boil. When a pump is made to operate upon hot water, it labours in vain to raise the liquid. This circumstance limits the heat of water injected into the boilers of steam-engines; or if the water is injected at a high temperature, it must receive its heat between the pump and the boiler. This is sometimes done, by causing the tube from the pump to pass through a vessel of waste steam.

SYPHONS.

245. Atmospheric pressure is very conspicuous in the case of the syphon.

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176. What is used to supply water to the boiler of a steam-engine, and why?

‾7. What effect has hot water upon a pump?

246. A syphon is a tube bent in a particular manner, and is used for drawing off liquors from casks, or water from reservoirs. One kind of syphon is represented in Figure 34, and consists of a tube bent into two equal limbs, each open at the extremity. If such a syphon be filled with water and inverted, so as to turn the two orifices downwards, the liquid will not run out, but remain suspended in the tube, because the pressure of the column of water within is not so great as the pressure of the air without, and thus its escape outwards is prevented. If one end be put into a vessel of water, the vessel will be emptied down to a level with the orifice. It is evident that, when one end of the syphon is inserted in water, the pressure of the atmosphere upon the surface of the water impels the liquid through the tube, and it could be forced upwards to an elevation of above thirty feet, or the height to which water rises in a vacuum. The diagram represents an instrument of this kind furnished with two cups, firmly attached to the ends, which, by retaining a portion of the liquid, keeps the syphon always full and ready for use.

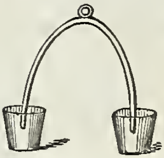
Figure 34.

247. Syphons are more commonly made with a long and short limb, as in Figure 35. On inserting the short limb into a vessel of liquid, and drawing the air out of the tube at the mouth A, the liquid will rush out in a stream, and continue flowing till the vessel is emptied. The pressure upwards into the tube at A is the excess of the atmospheric pressure above the vertical pressure of the column of fluid AB : and the similar pressure at C is the excess of the atmospheric pressure above the vertical pressure of the column of fluid BC ; but

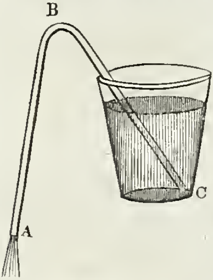

Figure 35.

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178. Explain the syphon and its use.
179. Explain the diagram.
180. Explain the second diagram.

the latter excess is evidently the greater, and hence the liquid in the vessel is necessarily forced upwards through the tube from C to B; and thus the vessel is drained of its contents. By placing a stopcock on the tube above A, the stream can be checked, and permitted to flow at pleasure. There are instances of towns being supplied with water by means of large syphons of this kind. In these cases the syphon is brought over a rising ground from a lake or fountain at some distance.

SYPHON SPRINGS.

248. Certain kinds of springs are accounted for on the principle of the syphon; they act from the combined effects

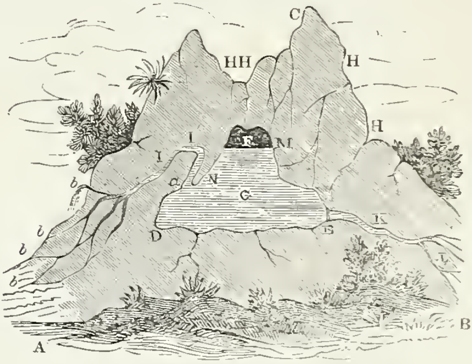

Figure 36.

of a vacuum and atmospheric pressure. The following are examples:—Let ABC, Figure 36, represent a mountain, and DEF a hollow in its centre containing water G, which flows to it through several small ducts, HHHH. Let II′ be a natural syphon, one end of which is connected with the water at *a*, and the other ramifies into diverse branches, issuing from the mountain at *bbbb*. Let K be also another

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181. What of syphon springs?
182. Explain the drawing.

stream issuing from the hill at L, but which, for the present, we shall suppose is closed at E. Now, if the hollow cavern be filled to the height M by the rivulets HHHH, it is evident that, on the principle of the syphon above described, the hollow will be emptied to the level N; and the water thus withdrawn will emerge from the mountain in the form of springs *bbbb*, because they are all at a lower level than that to which the water rises in the syphon at I′. When the whole has run off, they will then cease to flow until the hollow is refilled to the level M, when it will flow again, and thus the process goes on. This is what is termed an *intermitting spring*. Some springs, called *variable* or *reciprocating*, do not cease to flow, but only discharge a much smaller quantity for a certain time, and then give out a greater quantity. This arises from there being two hollows, one above the other, in the bosom of the mountain, the highest one having a runner, not of a syphon form, which joins the stream of the lower one beyond the bend, or inflection I′. This runner keeps the stream always supplied to a certain degree, although the lower cavity be dry. But when the latter is filled to M, the current is of course greatly augmented, which augmentation continues until the under hollow is again drained.

249. In some places there are springs which run freely in summer, or in dry weather, and almost stop in winter, or in wet weather. This is explained in the following manner:—Suppose the passage KL to be now open at E, and the water in the hollow to be very low, as it is in summer, or in dry weather—so low indeed that none can escape through the syphon II′—then the spring at L will flow constantly. If during wet weather, however, the cavern be filled to the level M, the syphon will act, and drain off the water: and if we suppose the mouth of the syphon to be lower than the outlet at E, and to drain off as much as the runners HHHH supply, it will allow none to issue from the orifice at L at all, for then E would be above the surface of the water.

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183. What variety of springs are named?
184. Recite the explanations given.

250. The orifice at L, supposing there was no other outlet from the mountain, may be taken as an instance of those springs, most common, which flow continually. The reservoir from which these are supplied is generally to be traced to some hill or range of hills in the neighbourhood, which from the quantity of rain, &c. collected by them, keep the internal cavity continually full, or nearly so. Springs cannot rise higher than the reservoir from which they are supplied, and fountains, which are springs that burst out at a level considerably lower than the water in the reservoir, do not rise so high, because when they issue from the orifice, they have the resistance of the air to overcome, which retards their ascent. The current also branches out laterally, and thus the force which impels it upwards is partly expended in giving it an oblique direction.

251. In some parts, intermitting springs have afforded an opportunity for designing individuals imposing upon the credulous. Taking advantage of the flowing and stopping of water-runs, these persons have gained credit to themselves by predicting the period when the events would happen which, from a few years' observation, would easily be learned.

PNEUMATICS CONTINUED.

BOILING POINT DETERMINED BY ATMOSPHERIC INFLUENCE.

252. The pressure of the atmosphere exerts a powerful influence over the forms in which matter presents itself to our senses. The force of gravity draws bodies towards the earth, and the atmospheric pressure, along with the property of cohesion of particles, serves to give them compactness or firmness. By removing the atmospheric pressure, by means of the air-pump or otherwise, some solid bodies will become soft or partially liquid, and liquid bodies will evaporate and assume an aëriform condition.

253. The degree of pressure exerted by the atmosphere, and also the degree of general temperature, are adjusted by

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185. What of springs and fountains as to their height?
186. What changes result from removing the atmospheric pressure?

nature to produce and sustain the present external properties of matter. The atmospheric pressure is not so great as to prevent spontaneous evaporation from liquids, but is sufficient to moderate its action, and harmonize it with other phenomena in nature.

254. Liquids spontaneously evaporate at all temperatures from the freezing point upwards, though at a much slower rate at a low than a high temperature. When the liquids attain that temperature at which the phenomenon of boiling or ebullition occurs, vaporization is in greatest activity, and speedily but gradually carries off the particles of fluid into the atmosphere.

255. The degree of heat at which a liquid body boils, depends on the amount of atmospheric pressure, and also on the nature of the body itself. The constituent particles of certain liquids cohere more closely together than others, and a greater heat is required to separate them.

256. Subject to the common pressure of the atmosphere, ether, which is a volatile liquid used in medicine, boils at a temperature of 104 degrees, alcohol or strong spirits at 170 degrees, water at 212 degrees, tallow at about 600 degrees, and mercury at 692 degrees. If we either increase or diminish the incumbent pressure as given by the atmosphere, the boiling points of these, as well as all other liquids, are immediately changed.

257. By increasing the pressure on liquids beyond that given by the atmosphere, a greater degree of heat is required to make them boil. This circumstance is taken advantage of in the case of certain preparations, in which a higher temperature than 212 degrees is required. For example, to extract properly the gelatinous and oily matter from bones, they must be boiled with a quantity of water in a strong closed vessel; the steam consequently does not escape, but presses on the water, and so keeps it from boiling till a very high temperature has been attained. The same end would be gained by forcing in air upon the water

187. What of evaporation and vaporization?
188. Upon what does the boiling point of liquids depend?
189. Name the boiling point of different liquids.
190. How may greater heat be attained without boiling?

to the required pressure, as for instance, to a pitch of pressure of 30 lbs. to the square inch, or two atmospheres.

258. By endeavouring to boil water at a point below the level of the sea, the same result is observable. It is found that in a diving-bell sunk to a depth of sixty-eight feet in the sea, water does not boil till it attain a temperature of 272 degrees.

259. When the atmospheric pressure is removed, a contrary effect is observable. At the summit of Mont Blanc water boils at a temperature of 187 degrees. In certain preparations in the arts, such as distilling spirits, and extracts of herbs (for scents and medicines), it is important to have the vaporific point at a comparatively low temperature. In all such cases the preparation is effected in a vacuum formed by an air-pump connected with the boiling liquid. Some liquids may thus be boiled at a temperature of from 90 degrees to 100 degrees. Unless for this ingenious arrangement, the delicate properties of some medicines could not be procured by distillation, for a heat of 212 degrees would injure or destroy them.

STEAM.

260. Steam produced from boiling water is a transparent, colourless, and invisible substance, like air. If we could look into the boiler of a steam-engine, we should see nothing but the water in a state of ebullition. The white cloudy-looking matter which is emitted in the form of vapour, is moisture produced by the partial condensation of the steam in the atmosphere—taking the form of vapour is a step towards becoming liquid again.

261. A cubic inch of water produces exactly a cubic foot, or 1728 cubic inches, of steam, at 212 degrees of temperature; in other words, when water is transformed into steam, it occupies 1728 times its former bulk. In this expanded condition steam is of a less specific gravity than air. Its density is expressed by 0·625, that of air being 1

191. How may they be made to boil at lower temperatures?
192. Define steam, and vapour.
193. What of the bulk and specific gravity of steam?

262. The elastic force of steam in the process of heating—that is, the force with which it seeks to expand—differs at different temperatures. At first the force is inconsiderable, but it rapidly increases as the temperature is raised. At a temperature of 212 degrees, the elastic force is 15 lbs. on the square inch of the containing vessel, or equal to the external pressure of the atmosphere; at 250 degrees it is 30 lbs., at 272 degrees it is 45 lbs., and at 290 degrees it is 66 lbs.

263. As the elastic force increases, so does the density of the steam; the elastic force, indeed, always corresponds to the density; because the more steam which is packed into a given bulk, the greater must be its expansive force.

264. In reference to steam-engines, steam of different degrees of elastic force is employed. When the steam is not suffered to have any communication with the atmosphere, but is condensed in a vacuum connected with the engine, the steam employed is called *low pressure*. In most instances its elastic force is not more than 15 lbs. on the square inch; and as this is counteracted by an equal pressure from the atmosphere, there is no danger of the boiler exploding. When the steam is not condensed in this manner, but is suffered to rush out in puffs into the atmosphere, it must possess a force not only to move the engine, but to overcome the atmosphere which presses upon it in its emission. To possess the degree of force called high pressure, the steam is raised to a temperature of from 250 degrees to 272 degrees, producing an elastic force of from 30 to 45 lbs. on the square inch of the boiler. Hence the danger of explosion in working high-pressure engines.

LATENT HEAT.

265. The change of form in bodies, from solid to liquid, and liquid to gaseous, or from liquid to solid, and gaseous

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194. What of the elastic force and density of steam?
195. Explain the safety of low pressure engines, and why.
196. Whence the danger of high pressure?
197. What of a change of form in all bodies?

to liquid, is in all cases attended by a remarkable circumstance in relation to heat.

266. Heat or caloric, as already mentioned,* is an affection or quality pervading all things, but frequently concealed or *latent*, in which state it is in no respect obvious to our senses, and cannot be detected by the thermometer.

267. When solids become liquids, and when liquids become airs, latent heat is evolved, and combines with the newly formed substances. But this heat, though elaborated, is still latent, not perceivable by our senses or by the thermometer. When, on the other hand, liquids become solids and airs become liquids, as by condensation, the latent heat is instantaneously relieved from its disguise, and makes itself known.

These propositions may be exemplified as follows:—

268. When a vessel of water open to the atmosphere is placed on the fire, the water gradually becomes hotter till it reaches 212 degrees, when it boils; afterwards its temperature is not increased. Now, heat must be constantly entering from the fire, and combining with the water; as the water, however, does not become hotter, the heat must combine with that part of it which flies off in the form of steam; but the temperature of the steam is only 212 degrees, the same as the water from which it rises, and therefore this constantly adding heat does not obviously increase its temperature.

269. Thus, the steam which rises from boiling water becomes a receptacle for the heat which is constantly entering the liquid from the fire, and in this receptacle it remains in a dormant or latent state, till the steam is reduced to vapour or its elementary liquid, when the accumulated heat is instantaneously developed. The scald given by steam on its emission into the atmosphere, in the form of vapour, is well known to be far more severe than that given by boiling water. The deposition of the latent heat from

* LAWS OF MATTER AND MOTION, paragraph 78 to 81.

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198. Explain latent heat, and when it is evolved.
199. How is the fact exemplified, and what of scalds?

the vapour is the cause of this excess in the severity of the scald.

270. Dr. Black, professor of chemistry in the University of Edinburgh, made the discovery of the principle of latent heat, about the year 1757. The following was one of his experiments:—He put some water at a temperature of 50 degrees in a tin-plate vessel upon a red-hot iron. In four minutes it began to boil, and in twenty minutes it was all boiled off. During the first four minutes the water received an addition of 40½ degrees per minute, or altogether 162 degrees. If we suppose that it received as much per minute during the whole time of boiling, the caloric which entered into the water, and converted it into steam, would amount to 40½ multiplied by 20, which is 810 degrees.

271. Water may be heated, as already stated (257), to a temperature of more than 212 degrees, by laying a force upon it greater than that imposed by the atmosphere, or by simply confining the steam (allowing no emission of steam whatsoever), which has the same effect. By heating water in a strong cylindrical copper vessel, perfectly closed, called a Papin's Digester, the temperature of the water may be raised to 400 degrees without boiling. If the mouth of the vessel be suddenly opened while the water is in this state, part of the water will rush out in the form of steam, but the greater part remains in the form of water, and its temperature instantly sinks to 212 degrees; consequently, 188 degrees of heat have suddenly disappeared. This heat must have been carried off by the steam. Now, as only about one-fifth of the water is converted into steam, that one-fifth must contain not only its own 188 degrees, but also the 188 degrees lost by each of the other four parts; that is to say, it must have contained five times 188 degrees, or 940 degrees. Here, then, is a proof that steam contains at least 940 degrees of heat.

272. If one part of steam, at 212 degrees, be mixed with nine parts, by weight, of water at 62 degrees, the steam

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200. What was Dr. Black's experiment and its result?
201. How may water be heated beyond the boiling point?
202. By what instrument may this be done?
203. What calculations are made here?

instantly assumes the form of water, and its temperature, after mixture, is 178·6 degrees; consequently, each of the nine parts of water has received 116·6 degrees of caloric, and the steam has lost nine times 116·6 degrees, or 1044 degrees of caloric. But as the temperature of the steam is diminished by 33·4 degrees, we must deduct this sum, when there will remain rather more than 1000 degrees, which is the quantity of heat in the steam.

273. If a gallon of water be transformed into steam, and that steam allowed to mix with six gallons of cold water, the whole will be raised to the boiling point.

274. From these and other philosophical experiments, it has been ascertained that the latent heat in steam varies from 940 degrees to 1044 degrees; usually, it is reckoned to be about a medium between these extremes, or nearly 1000 degrees.

275. In proportion as steam is raised beyond a temperature of 212 degrees, the ratio of accumulation of latent heat becomes the greater, just as the steam becomes more dense and of greater elastic force. At a temperature of 290 degrees, steam will rush out, and deposit four times as much heat as it would do at 212 degrees. This has been ascertained by experiment.

276. To prove that all the heat above 212 degrees is latent in steam, it is only necessary to place a thermometer in a boiler, but in such a way that it can be seen through a strong piece of glass, or that it will act upon an external index. Thermometers with externally acting indices are common in steam boilers.

277. We can now comprehend why scalds from steam are so very violent. The steam, at 212 degrees, so long as kept within the boiler, rises to a temperature of nearly 1000 degrees the instant it comes in contact with the air or any substance on which it condenses itself. Our hand, therefore, on suffering a scald from steam, receives in less than a moment of time 1000 degrees of heat, which is sufficient to destroy the skin, and to inflict the severest pain.

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204. What is the latent heat in steam?
205. Explain the illustration here given.

278. In the process of evaporation which is less or more in constant activity over the globe, the aëriform moisture carries off latent heat from the liquid substances from which it rises. This is as perceptible by our sense of touch or feeling, as the deposition of heat in a scald. If we wet the back of our hand with water, we feel a sensation of cold from the evaporation which immediately ensues. If we use spirits instead of water, the evaporation will be more active, and the sensation of cold the more intense. The feeling of cold is caused by the withdrawal of heat from the part, which heat becomes latent in the rising vapour. Rooms are cooled by sprinkling water on the floor; the coolness being caused by the withdrawal of heat in the evaporation which ensues.

279. The principle of latent heat is essential in the economy of nature. The mode of its evolution and absorption has the effect of preventing sudden alterations in the condition of solids and liquids. Instead of water suddenly exploding in steam on attaining the boiling point, the process of transformation into air is gradual, on account of the steam becoming the depository of the accumulating heat. So, when water freezes, it does not do so instantaneously on attaining the freezing point, because it has to absorb the heat in the water, and seal it up in a latent state, ready to be developed again in a manner equally gradual on the melting of the ice.* Thus the evolution and absorption of latent heat form an important principle in regulating change of condition in substances, both in the economy of nature and of art.

PNEUMATICS CONTINUED.

ALTERATION OF TEMPERATURE IN AIR.

We have now to consider the influence of change of temperature in air.

* LAWS OF MATTER AND MOTION, paragraph 117.

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206. What examples of latent heat are cited ?
207. How shown in nature and art ?

280. Air, like water, is heated by the sun's rays, and also by artificial means.

281. The heat existing in any given bulk of air depends on the quantity or weight of air in the bulk.

282. In some situations the air is dense, and in others it is thin—it is most dense where the atmospheric pressure is greatest, or at the level of the sea.

283. If we take a pound weight of air near the sea's level, and another pound weight at a spot a mile above the sea, we shall find that each pound contains precisely the same quantity of heat; but in the case of that taken near the sea, the air will feel warm, and in the case of the other, the air will feel cool. This seems paradoxical, yet it is a truth. A pound of air, taken near the sea, is compact in substance, and goes into a comparatively small bulk; but that taken from a high part of the atmosphere is thin, and occupies a much larger space.

284. This explains why the thin air on high grounds is seemingly colder than in low situations. Aloft, the air is as warm as it is below, but there is less of it; the particles are more widely asunder, and this produces the effect of a greater coldness. Properly speaking, the cold in high situations arises from the want of air, rather than from the air itself.

285. In the warmest regions of the globe, the air is cold at the tops of high mountains, merely because the air is there thin, and incapable of forming a medium for the retention of heat from the sun's rays.* In every country there is a point of altitude at which water freezes on all occasions, whether summer or winter. In Europe, this point—called by some the snow-line, or point of eternal snow—is from five to six thousand feet above the level of the sea; in the hot regions of Africa and America, it is at

* The thin air in the higher regions of the atmosphere is understood to contain heat in a latent condition, but this no way affects the above argument.

208. By what means is air heated?
209. What relation between temperature and density?
210. How is the cold in high situations explained?
211. What of the snow-line in different countries?

fourteen thousand feet. At these points of altitude respectively, snow lies constantly unmelted on the mountain ridges and summits. The same effect is observable on ascending in a balloon. In the warm region of Hindostan, the atmosphere is as cool and pleasant at a certain height on the Himalaya mountains as it is in the northern part of Europe.

286. In this manner we see that atmospheric pressure affects the temperature in the air around us.

287. Inasmuch as heated water, from its specific lightness rises to the top in any containing vessel, while the colder particles of the liquid sink to the bottom (156), so does heated air from precisely the same cause rush upwards, while the colder atmosphere sinks to replace it.

288. It might be inferred from this that the heated air near the sea and other low situations would mount into the higher regions of the atmosphere, and there sustain a considerable warmth. Heated air certainly rises into the upper strata of the atmosphere, but on rising it expands, and by that very circumstance its heat has no sensible effect in meliorating the cold. According to the constitution of things, it is impossible to warm the higher regions of the air. The quantity of heat which daily ascends all over the globe is immense, but it never in the smallest degree raises the temperature of the upper air, being thrown off by radiation into surrounding space, or going into a latent condition.

289. The air differs in temperature at different parts on the same level, in consequence of the constant daily shining and withdrawal of the sun's rays. During the day the air is warmed, during the night it becomes cool.

290. The difference of temperature produced in this or any other manner, leads to constant disturbance in the atmosphere. Here the air is rising, there it is sinking or rushing sidewise to supply the deficiency; in short, its motions are indescribably various, all in consequence of the ever-shifting temperature of the atmosphere.

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212. What analogy between liquids and gases?
213. Why cannot the higher regions be heated?
214. Explain the difference between day and night, and why?

AIR IN MOTION—WINDS.

291. The currents of the air are called winds. Winds originate from any cause which occasions a portion of the atmosphere to expand or contract. Change of temperature, as being the principal cause of these expansions and contractions, is the principal cause of winds. The manner of the origin of these winds is very simple, and is completely exemplified within our daily experience. When the door of a heated apartment is thrown open, a current of air is thereby immediately produced: the warm air from the apartment passing out and the cold air rushing in.

292. Some winds occur from the following cause:—When a condensation of vapour in the atmosphere suddenly takes place, giving rise to clouds which speedily fall in rain, the temperature of the surrounding air is sensibly altered, and the colder rushing in upon the warmer, gives rise to a sudden gust of wind. For this reason, a cold heavy shower passing overhead, with a hasty fall of snow or hail, is often attended with a violent and sudden gust of wind, which ceases when the cloud disappears, but is renewed when another cloud, sweeping along in the same direction, brings with it a fresh blast. Accordingly, a gust of the wind is universally considered to be a prognostic of rain, because it indicates that a change is taking place in the temperature of the atmosphere, owing to the vapour in its higher regions being condensed into rain-clouds.

293. The winds which blow in Great Britain, the United States, and other temperate parts of the earth, generally originate in some atmospheric disturbance on the ocean or in tropical climates, and therefore cannot possibly be prognosticated with any degree of certainty.

294. The most remarkable winds are those which traverse the ocean steadily in one direction, and are called "trade-winds," from their use to mercantile navigation. In order that we may distinctly understand the cause and na

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215. Define wind and its causes.
216. Explain the connection between winds and rain.
217. Explain the trade-winds and their source.

ture of the trade-winds, it is necessary to bear in mind that the portion of the globe extending 23½ degrees north and 23½ degrees south from the equator, forming the torrid zone, is constantly beat upon by the sun's rays in a direction so little oblique, that the most intolerable heat might there be anticipated. This being premised, and it being also remembered that the earth revolves daily from west to east, the cause of the trade-winds will be readily understood.

295. The rays of the sun as the earth passes round beneath them, obviously rarefy, by the heat they impart, the air beneath, and the air so rarefied rises into the higher regions of the atmosphere. While this takes place, the colder air from the adjoining temperate zones rushes in to supply its place. But it is from the polar regions, north and south, that these colder currents originally come; and did the earth remain at rest, such would be their obvious direction. Instead of this, however, north of the equator the direction of the trade-winds is from the north-east; south of the equator, from the south-east; the cause of which is thus explained:—The velocity with which the surface of the earth revolves at the poles, is inconsiderable, if at all appreciable, but increases as we advance, and is at its maximum at the equator; the winds, in sweeping from the poles, do not acquire a corresponding velocity with the motion of the earth as they advance towards the equator; therefore moving more slowly than the earth, they are in some measure left behind, or appear to an observer as if moving in a direction contrary to the rotation of the earth, namely, from east to west. While the trade-wind thus blows upon the surface of the earth, there is no doubt that an opposite current, that of the rarefied air which has ascended, flows towards the poles at a great elevation in the atmosphere.

296. The external limits of the trade-winds are 30 degrees north and 30 degrees south of the equator; but each limit diminishes as the sun advances to the opposite tropic. The larger the expanse of ocean over which they sweep,

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218. What theory is stated to account for them?
219. What of their limits and how modified?

the more steadily do they blow; accordingly they are more steady in the Pacific than in the Atlantic, and in the South than in the North Atlantic Ocean. Within the region of the constant trade-winds, rain seldom occurs, but it falls abundantly in the adjoining latitudes. The reason is, that rain is produced by the sudden mixture of air of different temperatures charged with moisture; but the constant circulation and intermixture of the air from the upper strata of the atmosphere, or ground current, maintains so equal a temperature in these latitudes as not to occasion the condensation of vapour which is necessary for the production of rain. Besides which it is plausibly enough alleged, that the aqueous vapour constantly flows off in the current of the equatorial wind into the adjoining temperate zones. Within the limits of the trade-winds, contrary to what might have been anticipated from the latitude, the atmosphere is peculiarly cool and refreshing.

SEA AND LAND BREEZES.

297. In most countries near the shores of the sea, but particularly in tropical climates, there are periodical winds called sea and land breezes; they occur in the following manner:—During the day, the wind blows for a certain number of hours from the sea to the land; but when the evening arrives, it changes its direction, and blows as many hours from the land to the sea. In some countries the sea-breeze sets in about seven or eight in the morning, and is strongest at noon, but continues very sensible until three o'clock, when the surface of the sea will be observed to exhibit ripples of a deep blue colour. After this, at six in the evening, the land-breeze commences. The sea now assumes a greenish hue; and this breeze continues until eight the next morning. The cause of this alteration may be readily explained. During the day, the air over the surface of the earth is more heated by the rays of the sun than that over the surface of the sea; because the earth, from its greater density, comparative state of rest, and

220. What of rain and the trade-winds?
221. Explain the phenomena of sea and land breezes.

numerous elevations, absorbs the sun's rays sooner, and is more heated than the sea, which, from its state of constant motion and transparency, imbibes the warmth very intimately, though more slowly. Accordingly, when the sun, having risen above the horizon, has thus imparted a sufficient degree of warmth to rarefy the body of air over the land, the air so rarefied ascends into the higher regions of the atmosphere, while that over the surface of the sea, being scarcely at all rarefied, rushes in to supply its place. Hence, a sea-breeze, or current of air from the sea to the land, at this time prevails; but when the sun again begins to sink below the horizon, the body of air over the surface of the land becomes rapidly cold, because the earth itself, by radiation, parts very quickly with the warmth it had absorbed. Then the land air, being below the temperature of the sea air, rushes in to supply its place, and thus, during the night, a land-breeze, or a current of air from the land to the sea, is produced.

298. When the sea-breeze first sets in, it commences very near the shore, and gradually extends itself farther out at sea, and, as the day advances, becomes more or less hot. Hence, the sails of ships have been observed quite becalmed six or eight miles out at sea, while at the same time a fresh sea-breeze has been blowing upon the shore. The cause of this is obvious; for it is natural to suppose that the mass of air nearest the land will be the first to rush in, for the purpose of supplying the place of the air which is rarefied immediately above it. On this account the effect of the sea-breeze is said not to be perceptible at a distance of more than five or six leagues from the shore, and for the most part becomes fainter in proportion to its distance from land. The distance, on the other hand, to which the land-breeze extends in blowing across the sea, depends on the more or less exposed aspect of the coast from which it proceeds. In some places this breeze was found by Dampier brisk three or four leagues off shore; in other places not so many miles; in others, again, it scarcely extended without the rocks. The sea-breeze, from blowing over a

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222. What peculiarities in these sea breezes?

more open tract, is always stronger than the land-breeze; but it is observed that the land-breeze is much colder than the sea-breeze. Furthermore, it has been noticed that the tendency of the land-breeze at night has almost invariably a correspondence with the sea-breeze of the preceding or following day. Unless for the periodical refreshing cool breezes from the sea, the West India islands, and generally all hot countries, would scarcely be habitable for the white races of men.

299. The most dangerous winds to the navigator are those which occur in sudden gusts, or squalls, and for the approach of which the sharpest outlook is required. When the squall is in the form of a violent tempest, accompanied by rain, lightning, and thunder, it receives the name of a hurricane. Hurricanes occur most frequently and with the greatest violence in tropical climates, because, in consequence of the very great heat which there prevails, the rarefaction of the air, and also the condensation of the vapour it contains into rain-drops, take place more suddenly and completely than in more temperate regions. By this means the electricity of the atmosphere—that subtle fluid which seems to pervade all bodies, and which universally seeks its own equilibrium—is disturbed, and no longer maintains an equal distribution through the aërial vapour. It accumulates in vast quantities in one mass of vapour or cloud, while in another it is deficient; and, consequently, to regain its equilibrium, it flashes in the form of lightning from the surcharged cloud, to the cloud that is undercharged, or to the earth itself. Hence, hurricanes are always attended with electrical manifestations, which add greatly to the tragical horrors of the spectacle they exhibit.

VENTILATION.

300. Ventilation (from *Ventus*, the Latin word for wind) is the art of preserving the air of apartments in a pure condition.

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223. What of hurricanes and their causes?
224. What agency has electricity in these?
225. Define ventilation and its importance.

301. This is an arrangement of the utmost importance to health and comfort. A plentiful supply of pure air is necessary for respiration, because the air on being used by the lungs is expelled in a deteriorated condition, and unfit for being again inhaled.* If apartments, therefore, are not properly ventilated, the air becomes foul from the respired air, as well as, perhaps, from impure exhalations and rarefaction from heat.

302. The air so deteriorated may not commonly, produce immediate death, but it injures the health of those who live amongst it, and is the fertile cause of deadly distempers, such as fevers, cholera, and plague.

303. Besides being indispensable for breathing, pure air is necessary for the support of combustion. Any fire deprived of a supply of air languishes and becomes extinguished. The kind of air best adapted for the supply of a fire is that which is most pure and cold, as it contains more oxygen in any given quantity. Oxygen is the essential element both for breathing and combustion; and when it is supplied

* It is calculated that a man in ordinary circumstances consumes about 45,000 cubic inches, or nearly 15,000 grains, of oxygen in twenty-four hours. A quantity of carbonic acid gas is produced in some measure proportionate to this consumption. All the oxygen which is inhaled is not consumed; a small portion returns with the breath. The nitrogen of the air undergoes little or no change by being drawn through and expelled from the lungs.

"In combustion or burning, it is [also] the oxygen of the air alone which is used, the nitrogen remaining unaltered. It is in consequence of a chemical attraction subsisting between the burning body and the oxygen of the air, that the burning goes on, the oxygen undergoing a change from being chemically united with the combustible body, and being no longer able to support the combustion of that substance, while, at the same time, the combustible body is altered from being united to oxygen. Hence the reason why a lighted candle is immediately extinguishad if placed in a quantity of air from which the oxygen has been withdrawn, or in almost any situation where it cannot procure free oxygen ready to combine with the combustible body.

"Oxygen may be considered the essential, the active part of the air, the part which *does* every thing. It is the oxygen chicfly which is engaged, and becomes altered in all those chemical operations in which the air is concerned; the nitrogen seldom undergoes any alteration, acting chiefly as a damper, moderating the action of the oxygen, and preventing it from doing too much."—*Hugo Reid's Chemistry of Nature.*

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226. What dangers result from a want of it?
227. What element in air is essential to combustion?

in a sufficient quantity, the fire burns rapidly and brightly. The intense combustion produced by blowing a current of air into a fire by means of a pair of bellows, is well known. This intense combustion is produced by the extraordinary quantity of oxygen which is forced into the burning mass.

304. Fire deteriorates pure air as effectually as breathing it. The oxygen is consumed, and by a chemical change in substance, carbonic acid gas, which is unfit for respiration or combustion, is produced. Fire also heats and causes to expand the air which passes unconsumed through or near it. This expanded air, from its specific lightness, mounts upward, and endeavours to escape by any opening made for it above the fire place, while colder and more dense air rushes in to supply the deficiency.

305. Although carbonic acid gas is considerably heavier than pure air (171), it has a tendency when heated and expanded to mount upward along with the air which has been simply heated in its passage near the fire. Thus, by a fortunate provision, all impure air whatsoever may be carried off by expanding it by heat: in other words, the tendency which a heavy impure air has to sink, is overcome by increase of temperature; and in this manner our warmed breath and the warm bad air from our fires are equally caused to escape upwards, and leave room for a fluid suitable to our necessities.

306. Let it now be observed that a constant supply of air is necessary in apartments for two purposes—breathing, and combustion in the fire which is employed for heating or cooking; and let it further be noted, that means must be provided for the escape of the air after it has performed its office.

307. In common circumstances, the supply, such as it is, is kept up by means of the occasional opening of the door, and crevices in the floor and windows; the whistling of the air through the keyhole and other small openings, is an example of the activity of the atmosphere in rushing to supply the internal deficiency. The chimney is usually the only outlet.

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228. What analogy between this and respiration ?
229. Whence is our ordinary supply of air, and how changed ?

308. When a fire is lighted in an apartment, it heats and expands a certain quantity of air near it: the heated and expanded air rises: this causes a partial deficiency or vacuum around: the air at a distance rushes to restore the equilibrium: this rushing is in the form of a current towards the fire and chimney, and is commonly called *draught*.

309. The current of air so sustained through an apartment is generally sufficient for ventilation, but by coming in a sharp cold stream, it chills the person who is exposed to it; and hence many serious colds, rheumatisms, and similar affections. Where it can be conveniently done, it is better to supply air to the fire by a tube direct from the atmosphere, or at least to warm the air in a lobby, before entering the room.

310. In whichever manner air is supplied to the fire in an apartment, it is necessary that it have a passage sufficient for entry and dismission. If the room be so close as to be without the means of passage in and out for the air, the fire will speedily heat the air in an uniform degree, like that in a confined oven, and ultimately consume it, when the fire will go out.

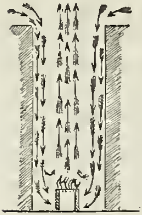
Fig. 37.

311. If all passages into the apartment be closed except the chimney, the fire will necessarily supply itself with fresh air by that channel, as in figure 37, in which the heated air is observed to be ascending directly over the fire, while a stream of pure and cold air is on each side descending the chimney to the fireplace beneath. This process of ascending and descending continues as long as no other inlet is allowed for the introduction of air to the fire.

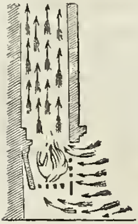
Fig. 38.

312. When a free passage is left for the entrance of air, and also a proper outlet above the fire, the air moves rapidly to the seat of combustion, passes through the fire, and ascends in an expanded volume in the

230. What of a draught?
231. Explain the diagram.

chimney. A representation of this process of supply and emission is given in Figure 38. In such a case the chimney is said to have a *good draught* or to *draw well;* but these terms are not correct. The draught is only the rushing of the air to fill the partial vacuum over the fire and in the chimney.

313. Such is the rapid consumption of fresh air in a fire, and the force with which a current moves to supply the deficiency, that air from the outer atmosphere will penetrate any accessible channel to get to the seat of consumption. In this respect, the air resembles water when any part of its volume is removed: the rest of the water hastens to restore a level throughout its mass.

314. In Figure 39 we have an example of this activity in the air, which represents a closed apartment with a channel for introducing fresh air behind the fireplace. The air rushes down this channel, passes through the fire, and then ascends in the chimney, and escapes. In this, as in similar cases, the air shows no reluctance to descend the channel; it indeed is compelled to do so, because the consumption caused by the fire has thinned the air, or caused a partial emptiness of air in the apartment, and the outer air being dense, must sink down to restore the equilibrium.

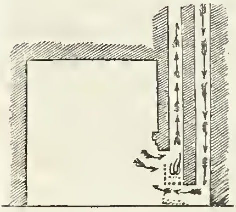
Fig. 39.

315. Smokiness in an apartment arises from various causes, but in most cases it can be traced to some impropriety in ventilation or malconstruction of chimney. Smoke consists of exceedingly small particles of coal or culm, and the vapour of bituminous matter and water, which are carried upward along with the ascending heated air from the fire: as long as the united mass retains its heat, the smoke is seen to rise in a compact body from the top of the chimney;

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232. What analogy is referred to?
233. Explain the first diagram.
234. Define smoke and its source.

shortly after which the heat is withdrawn by coming in contact with the cool external atmosphere, and the particles of culm, no longer supported, fall by their natural gravity to the earth.

316. One common cause of smokiness in an apartment is the want of a sufficient supply of air to the fire by the door, windows, or other lower openings. In common language, the room is *too close.* In this case the fire, as already stated, draws its supply from the chimney. While the heated air ascends, a stream of cold air descends, as in Figure 40, and in its descent it entangles the heated air loaded with smoke, and so brings down along with it a portion of the smoke into the apartment. An additional and properly situated opening in the room, will generally remove this cause of smokiness.

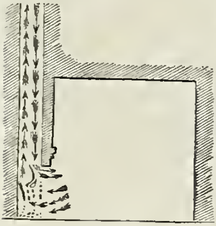

Fig. 40.

317. Another common cause of smokiness is too great a width of chimney, particularly beneath or near the fireplace. If the chimney be too wide throughout its length, the volume of heated air from the fire is insufficient to fill it; consequently it mounts sluggishly, is entangled with cold air entering both from above and beneath, and so partially returns, on the occurrence of winds, into the room. It is important for riddance of smoke that the chimney should contain only a heated column of air, which has a tendency to shoot rapidly upwards and escape. The longer such a column is (that is, the taller the chimney), the more difficult is it for the cold air above to retard its emission.

318. The most common cause o smokiness is the improper construction of the fireplace and lower part of the chimney. These are made so wide and open that cold air rushes into the chimney from the room *without passing through or near the fire.* This cold or heavy air mingles

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235. Explain the next diagram.
236. What other cause of smokiness is named ?
237. Name the most common cause.

with the heated smoky air, cools it, and brings back a portion of it into the room, in which the air is less dense than the external air. The remedy for this consists in narrowing the fireplace and throat of the chimney, so that all air shall first be heated before it commences its ascent. By doing so, the tendency in the heated air to rise completely overcomes the falling tendency in the particles of culm.

319. Smoke sometimes descends a chimney into a room from an adjacent chimney top, in which case it is usually called *back smoke.* This happens when the chimney and room contain air specifically lighter than the external atmosphere, and no inlet is allowed to restore the balance except the chimney. The air in the chimney cools and sinks, carrying an odour of soot with it into the room; and this being still insufficient to restore the equilibrium, a certain portion of atmospheric air also descends, bringing with it the smoke of the next house. If a room be left with an open chimney in summer, such a phenomenon is certain to occur. The air being warmer or more light outside during the day, the air of the room rushes up the chimney, leaving a partial emptiness; and at night there is a reverse motion, which brings the odour of soot, or perhaps smoke, along with it.

320. Smokiness may occur from the peculiar situation of a house, as for instance in a low dwelling near a tall pile of building, over which the wind is apt to gush with rapidity into the low chimney, as water falls over a precipice, and so overcoming all obstacles before it. But in by far the greater number of cases, the smokiness is dependent on those circumstances above mentioned, and might be entirely remedied by proper attention to a few simple rules in pneumatics. It must always be borne in mind that the cause of the smoke is something connected with the air; the smoke itself acting only a secondary part in the phenomenon.

321. Large apartments, such as churches, halls of public assembly, and schools, in which there is a large consump-

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238. What of smoke from the next house?
239. What of the relative situation of houses?

tion of air by respiration, require to be ventilated in a particular manner. The chimney, if they have one, is incompetent to carry off the foul air; and if they have no such outlet, the case becomes the more urgent. In many instances, the only means of ventilation which are employed is to let down the upper sashes of the windows; but this is a very clumsy mode of procedure, and may have dangerous effects from the currents of cold air which rush into the room. Besides, the plan is inefficacious in warm weather, when ventilation is most required, because the air outside being at the same temperature as that inside, there will be no rush either way: the whole will be in a state of stagnation.

322. To ventilate properly in these cases, the equilibrium of the air must be destroyed, in order to cause the foul air in the apartment to rush away to restore the atmospheric balance, and in doing so leave the room to be filled with fresh air. To accomplish this sure method of ventilation, the floor or some other lower part of the room must be perforated with innumerable small holes, through which currents of fresh air will be introduced from the exterior of the building. The ceiling must be similarly perforated

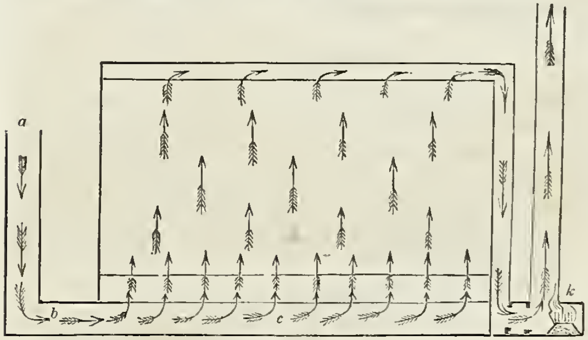

Fig. 41.

240. What of large apartments?
241. Explain the diagram.

with holes to carry off the ascending streams of breathed warm air. From above the ceiling, the air is carried along and down a channel to a fire, which highly rarefies it, and shoots it up a chimney along with the smoke from the fire. A representation of this method of ventilation, which is a device of the eminent chemist Dr. D. B. Reid, is given in Figure 41. The air enters by a channel *a b c*, thence ascends into the room, passes off at the ceiling, and is conveyed to the fire *k*, after which it ascends into the atmosphere. Valves or dampers may be placed in the channels to regulate the admission and emission of the air.

323. By thus establishing a fire somewhere adjacent, and opening a communication to it from an apartment, any kind of foul air may be effectually drawn off. On the same principle, a deep vat or pit containing carbonic acid gas, or any other air specifically heavier than the atmosphere, may be drained of its contents by plunging the lower extremity of a tube into it, and directing the other end to a fire. The fire will thus draw a portion of its supply of air from the pit, and so carry off the deletorious vapour.

324. When it would be inconvenient to ventilate by means of a fire, force may be employed to propel pure air into a confined apartment. We have an example of this in the case of the diving-bell.

THE DIVING-BELL.

325. The diving-bell is an iron box or apartment let down into water, and containing two or more men who are to be employed in some kind of mechanical operation at the bottom. It is chiefly used in building the foundations of piers in the sea, at a depth of from twelve to twenty feet below the surface, and in gathering at a much greater depth the valuable relics of vessels which have been wrecked and sunk.

326. Originally, the machine resembled a bell in figure; it is now generally shaped like a square box, narrower at the top than the bottom. It is made of iron, is perfectly

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242. Describe the use of a fire for ventilation.
243. Define a diving-bell and its use.

close except in the bottom or mouth, which is open, and is suspended by a strong chain from a crane on the deck of a vessel. It is from six to eight feet in height, with two or more glass lenses on the top to admit light from above when it is sunk, and there is a seat round the interior for the accommodation of those who descend.

327. Figure 42 is an outline representation of a diving-bell and its apparatus. B is the bell containing two men, one on the seat, and the other in the act of tying a rope R to a prostrate cannon, which, on giving a preconcerted signal, will be hauled up to a vessel on the surface of the water. C is the chain by which the bell is suspended, and T is a flexible leather tube by which fresh air is admitted into the bell. There is a stopcock on the mouth of the tube, by which the men can regulate the admission of air at pleasure. The bell does not touch the bottom, but hangs within a few inches or perhaps one or two feet of it, and therefore the men are provided with long leather boots, to protect them while they stand upon the bottom in the water.

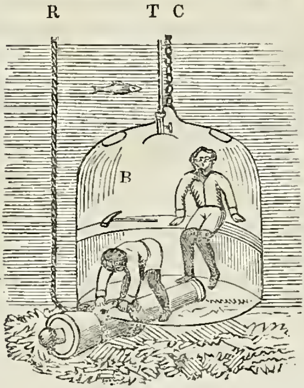

Fig. 42.

328. The manner in which the diving bell is supplied with fresh air, and freed from that which is impure, is most deserving of our attention.

329. When the bell is lowered, so as to touch and sink beneath the surface of the sea, it may be compared to the dipping of a tumbler, mouth downwards, in a vessel of water. In the same manner as the air within the tumbler keeps the liquid from filling it, so does the air within the

244. Explain the diagram.
245. How is a diving-bell supplied with air?

bell prevent the water from rising beyond a certain height. As the bell sinks, the air which it contains becomes gradually more compressed in bulk by the intrusion of water, and at a depth of thirty-four feet, the air is condensed into one-half of its natural dimensions. At this point, therefore, if no precautions were used, the bell would be half-filled with water. The means adopted to keep the water out consists in forcing in air through the already mentioned tube. On the deck of the superintending vessel is placed a powerful air condensing-pump, wrought by one or two men in constant attendance; and by this machine fresh air is injected into the bell, and kept at such a density as forces the water entirely out, or very nearly so.

330. The bell is freed of impure air by means of a separate tube and stopcock, fixed in its upper part; but in some cases such an arrangement is not considered necessary, as the expired air on becoming cool, and consisting chiefly of carbonic acid gas, descends by its greater weight to the bottom, and escapes round the lower edges of the bell, whence it rises in bubbles to the surface.

PNEUMATICS—CONCLUDED.

BUOYANT PROPERTY OF AERIFORM FLUIDS.

331. The atmosphere, as has been stated, possesses the property of buoying up bodies which, bulk for bulk, are lighter than itself. The law governing bouyancy in liquids is precisely the same as that governing bouyancy in aëriform fluids, and may here be repeated in reference to air.

332. *First.*—Any solid body immersed in a fluid displaces exactly its own bulk of fluid, and the force with which the body is buoyed up is equal to the weight of the fluid which is displaced. This refers to bodies of less density than air.

333. *Second.*—Any solid body of a greater density than air, when wholly immersed in that fluid, loses exactly as

246. How is impure air removed?
247. What of the buoyancy of air?
248. What analogy between air and water?

much of its weight as the weight of an equal bulk of air—that is, of the air which it displaces.

As these propositions have been sufficiently exemplified in a preceding part of the present work, from paragraph 89 to 108, and as the fluid support of air is in principle the same as that of water, little additional explanation is here required upon the subject.

334. The support afforded to bodies in the atmospheric fluid by its resistance is very evident from many appearances in nature, as the support of vapours or clouds, the rising of smoke and fine particles of dust, and the flying of birds; in art, it is exemplified by the flying of a boy's paper kite, the rising of soap-bubbles, and its buoyant property by the floating of balloons.

335. The flight of birds is not accomplished altogether by the buoyant property in the air. These animals support themselves by striking their wings against the fluid through which they are passing, and this friction, along with the property of buoyancy in the atmosphere, sustains them at any height to which they are pleased to ascend. Birds do not generally fly above half a mile in height, and seldom above a few hundred yards. At considerable elevations the air is so specifically light, as to be unsuitable for their easy support. Those which rise to the higher regions of the atmosphere, as for instance the eagle, are provided with large wings, which enable them to support themselves in the comparatively thin fluid in which they move. A small bird, when let out from a balloon, at the height of three miles, drops almost like a plummet, till it arrive in a fluid against which its little wings can take effect.

336. The buoyant property of the air thus obviously diminishes in proportion as it becomes less dense; and there is a point above which the lightest imaginable body or particle of matter would inevitably sink. By this means, independently of terrestrial attraction, an effectual limit has

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249. What examples of buoyancy are named?
250. What of the flight of birds?
251. What of the higher regions of the air?

been set to the distance attainable by substances from the surface of our planet. Not an atom of matter, since the period of the creation, has been suffered to escape beyond the higher regions of the atmosphere, or which has not in making the attempt been brought back to the earth.

337. The support given to bodies by the atmosphere diminishes their apparent weight, in the same manner as the apparent weight of bodies is diminished in water. A stone is moved more easily in water than in air, and so likewise is it moved more easily in air than in a vacuum.

338. The diminution in weight of a body in air, as already stated (334), is equal to the weight of the bulk of air displaced. Thus, if an object which displaces one grain of air, weigh a pound in a vacuum, it will weigh one grain less than a pound in air, and therefore one grain will require to be added to it to make up the apparent deficiency.

339. The weight of air displaced by any merchantable object is so exceedingly trifling as not to be worth reckoning in ordinary circumstances. Strictly speaking, however, that weight of air has an influence in the value of the transaction. In all cases in which the object weighed is more bulky than the weight employed to balance it, a certain quantity must be added to overcome the force with which it is buoyed up by the atmospheric fluid.

340. A pound of feathers lightly piled together contains somewhat more weight than a pound of lead. We may prove that such is the case, by taking the apparent pound of feathers and forcing them into a small bulk in an air-tight covering, and then weighing them again, when it will be perceived that they will weigh a little more than a pound. In strict justice to seller and buyer, all commodities should either be weighed in vacuo, or balanced against weights of equal bulk.

BALLOONS.

341. The light heated air which escapes from a fire, ascends, and is buoyed up by the more dense air beneath.

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252. What of the weight of air, and the illustrations?
253. Explain the principle of balloons.

Hydrogen or any other gas of a less specific gravity than air, in the same manner ascends and floats in the atmosphere at the height at which it finds air of its own specific gravity.

342. On the same principle, if heated air or any light gas be inclosed in a large silk bag, it will ascend in the atmosphere till it reach a region of air which is incapable of supporting it. Thus, a soap-bubble inclosing warm air readily ascends to the ceiling of an apartment. If the bubble be made with cold water, it will sink instead of rising.

343. A balloon is a bag made of fine varnished silk, and of such a magnitude that the difference betwixt the weight of its contents and that of the displaced air is sufficient to support the weight of the silk and the other parts of the apparatus.

344. Balloons were originally made to rise by being filled with heated air from a fire hung beneath them; but this dangerous and inconvenient practice was in course of time superseded by the use of hydrogen gas, one of the lightest airs which can be prepared. Hydrogen gas has latterly been succeeded by carburetted hydrogen, which though not so light, is more easily obtained, being the gas with which towns are now generally lighted.

345. Employing a moderately pure and light gas, the contents of a balloon may be estimated to weigh only an eighth of the weight of the atmosphere, bulk for bulk; and hence, after adding another eighth for weight of apparatus, it will ascend with a force of six-eighths; in other words, if the gas and apparatus weigh two pounds, the balloon will lift from the ground a weight of other six pounds.

346. The force with which a balloon will ascend is therefore to be calculated by measuring its capacity in cubic feet, and comparing the result with an equal bulk of atmospheric air: the difference of weight is the buoyant force of the balloon.

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254. How were they formerly made to rise?
255. What gas is now employed, and why?
256. How is its force of ascent calculated?

347. Of aërostation, or the art of moving through the air in balloons, great expectations were originally entertained, but the experience of half a century has proved that it is of no practical value. Its only use is the exhibition of an interesting principle in pneumatics. A balloon constructed in the best known manner, and moving upwards with a powerful force, is subject to the following drawbacks:—

348. As the balloon ascends, its contents expand in consequence of the increasing rarefaction of the atmosphere; if, therefore, it has been entirely filled when on the ground, a portion of the gas must be allowed to escape as it rises, otherwise it will burst. At the height of 3000 feet, the atmosphere is a tenth degree less dense than on the surface of the earth; hence the gas expands a tenth in bulk, and a tenth must be suffered to escape. This amounts to 8000 feet of gas in a balloon containing 80,000 feet; calculating the gas at 36 lbs. per 1000 cubic feet, the loss incurred by the escape at this limited height would be equal to 288 lbs. of buoyant power. As the atmosphere becomes the more rare as the machine ascends, the expansion proceeds, more gas must be emitted, and more buoyant power lost.

349. Again, at the approach of night, upon the passage through clouds, or under the influence of a shower of rain, a large quantity of moisture becomes absorbed by the net which encloses the balloon and other apparatus, frequently to the extent of two or three hundred-weight, requiring an immediate discharge of ballast to that amount, to prevent the balloon from being borne to the ground. As the morning approaches, or the influence of increasing heat begins to be felt, the moisture becomes dissipated; and there being no means of recovering the lost ballast, the balloon rapidly rises in the air, its contents expanding in the ascent, and rendering further liberations of gas necessary to prevent explosion. These alternations continuing to operate more or less frequently, it is evident that they must soon put an end to the buoyant power, however great originally, and

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257. What disadvantages attend upon balloons?

forcibly terminate the excursion through the air. Such are the principal causes which affect the continuance of aërial voyages for any length of time, and along with the contending effects of winds, against which there can be no preventive, render aërostation only a matter of amusement to a public assemblage.

TO THE FRIENDS OF EDUCATION.

The publishers of this series of mathematical works by Professor CHARLES DAVIES, beg leave respectfully to ask of teachers and the friends of education a careful examination of these works. It is not their intention to commend, particularly, this Course of Mathematics to public favor; and especially, it is not their design to disparage other works on the same subjects. They wish simply to explain the leading features of this system of Text-Books—the place which each is intended to fill in a system of education—the general connection of the books with each other—and some of the advantages which result from the study of a uniform series of mathematical works.

It may, perhaps, not be out of place, first, to remark, that the author of this series, after graduating at the Military Academy, entered upon the duties of a permanent instructor in that institution in the year 1816, and was employed for the twenty following years in the departments of scientific instruction. At the expiration of that period he visited Europe, and had a full opportunity of comparing the systems of scientific instruction, both in France and England, with that which had been previously adopted at the Military Academy.

This series, combining all that is most valuable in the various methods of European instruction, improved and matured by the suggestions of more than thirty years' experience, now forms the only complete consecutive course of Mathematics. Its methods, harmonizing as the works of one mind, carry the student onward by the same analogies and the same laws of association, and are calculated to impart a comprehensive knowledge of the science, combining clearness in the several branches, and unity and proportion in the whole. Being the system so long in use at West Point, and through which so many men, eminent for their scientific attainments, have passed, it may be justly regarded as our NATIONAL SYSTEM OF MATHEMATICS. Scholars and students who have pursued this course, will everywhere stand on the highest level with reference to the estimates which themselves and others will form of this part of their education.

The series is divided into three parts, viz.: First—ARITHMETICAL COURSE FOR SCHOOLS. Second—ACADEMICAL COURSE. Third—COLLEGIATE COURSE.

The Arithmetical Course for Schools.

I. PRIMARY TABLE-BOOK.
II. FIRST LESSONS IN ARITHMETIC.
III. SCHOOL ARITHMETIC. (Key separate.)

PRIMARY TABLE-BOOK.

The leading feature of the plan of this work is to teach the reading of figures that is, so to train the mind that it shall, by the aid of the eye alone, catch instantly the idea which any combination of figures is intended to express.

The method heretofore pursued has aimed only at presenting the combinations by means of our common language: this method proposes to present them purely through the arithmetical symbols, so that the pupil shall not be obliged to pause at every step and translate his conceptions into common language, and then retranslate them into the language of arithmetic.

For example, when he sees two numbers, as 4 and 8, to be added, he shall not pause and say, 4 and 8 are 12, but shall be so trained as to repeat 12 at once, as is always done by an experienced accountant. So, if the difference of these numbers is to be found, he shall at once say 4, and not 4 from 8 leaves 4. If he desires their product, he will say 32; if their quotient, 2: and the same in all similar cases.

FIRST LESSONS IN ARITHMETIC.

The First Lessons in Arithmetic begin with counting, and advance step by step through all the simple combinations of numbers. In order that the pupil may be impressed with the fact that numbers express a collection of units, or things of the same kind, the unit, in the beginning, is represented by a star, and the child should be made to count the stars in all cases where they are used. Having once fixed in the mind a correct impression of numbers, it was deemed no longer necessary to represent the unit by a symbol; and hence the use of the star was discontinued. In adding 1 to each number from 1 to 10, we have the first ten combinations in arithmetic. Then by adding 2 in the same way, we have the second ten combinations, and so on. Each ten combinations is arranged in a separate lesson, throughout the four ground rules, and each is illustrated either by unit marks or a simple example. Thus the four hundred elementary combinations are presented, in succession, in forty lessons,—a plan not adopted in any other elementary book.

SCHOOL ARITHMETIC.

This work begins with the simplest combination of numbers, and contains all that is supposed to be necessary for the average grade of classes in schools. It is strictly scientific and entirely practical in its plan. Each idea is first presented to the mind either by an example or an illustration, and then the principle, or abstract idea, is stated in general terms. Great care has been taken to attain simplicity and accuracy in the definitions and rules, and at the same time so to frame them as to make them introductory to the higher branches of mathematical science. No definition or rule is given until the mind of the pupil has been brought to it by a series of simple inductions, so that mental training may begin with the first intellectual efforts in numbers

The Academic Course.

I. **THE UNIVERSITY ARITHMETIC.** (Key separate.)
II. **PRACTICAL GEOMETRY AND MENSURATION.**
III. **ELEMENTARY ALGEBRA.** (Key separate,)
IV. **ELEMENTARY GEOMETRY.**
V. **DAVIES' ELEMENTS OF SURVEYING.**

Those who are conversant with the preparation of elementary text-books, have experienced the difficulty of adapting them to the wants which they are intended to supply. The institutions of instruction are of all grades from the college to the district school, and although there is a wide difference between the extremes, the level in passing from one grade to the other is scarcely broken. Each of these classes of seminaries requires text-books adapted to its own peculiar wants; and if each held its proper place in its own class, the task of supplying suitable text-books would not be so difficult. An indifferent college is generally inferior, in the system and scope of instruction, to a good academy or high-school; while the district-school is often found to be superior to its neighboring academy.

Although, therefore, the University Arithmetic and the Practical Geometry and Mensuration, have been classed among the books appropriate for academies, they may no doubt be often advantageously studied in the common-school; so also with the Algebra and Elementary Geometry. The Practical Geometry and Mensuration, containing so much practical matter, can hardly fail to be a useful and profitable study.

DAVIES' UNIVERSITY ARITHMETIC.

The scholar in commencing this work, is supposed to be familiar with the operations in the four ground rules, which are fully taught both in the First Lessons and in the School Arithmetic. This being premised, the language of figures, which are the representatives of numbers, is carefully taught, and the different significations of which the figures are susceptible, depending on the places in which they are written, are fully explained. It is shown, for example, that the simple numbers in which the unit increases from right to left according to the scale of tens, and the Denominate or Compound Numbers, in which it increases according to a different scale, belong in fact to the same class of numbers, and that both may be treated under a common set of rules. Hence, the rules for Notation, Addition, Subtraction, Multiplication, and Division, have been so constructed as to apply equally to all numbers. This arrangement is a new one, and is deemed an essential improvement in the science of numbers

In developing the properties of numbers, from their elementary to their highest combinations, great labor has been bestowed on classification and arrangement. It has been a leading object to present the entire subject of arithmetic as forming a series of dependent and connected propositions; so that the pupil, while acquiring useful and practical knowledge, may at the same time be introduced to those beautiful methods of exact reasoning which science alone can teach.

Great care has been taken to demonstrate fully all the rules, and to explain the reason of every process, from the most simple to the most difficult. The demonstration of the rule for the division of fractions, on page 147, is new and considered valuable.

The properties of the 9's, explained at page 93, and the demonstration of the four ground rules by means of those properties, are new in their present form, and are thought worthy of special attention.

In the preparation of the work, another object has been kept constantly in view; viz., to adapt it to the business wants of the country. For this purpose, much pains have been bestowed in the preparation of the articles on Weights and Measures, foreign and domestic—on Banking, Bank Discount, Interest, Coins and Currency, Exchanges, Book-keeping, &c. In short, it is a full treatise on the subject of Arithmetic, combining the two characteristics of a scientific and practical work.

Recommendation from the Professors of the Mathematical Department of the United States Military Academy

In the distinctness with which the various definitions are given—the clear and strictly mathematical demonstration of the rules—the convenient form and well-chosen matter of the tables, as well as in the complete and much-desired application of all to the business of the country, the "University Arithmetic" of Prof. Davies is superior to any other work of the kind with which we are acquainted. These, with the many other improvements introduced by the admirable scientific arrangement and treatment of the whole subject, and in particular those of the *generalization* of the four ground rules, so as to include "simple and denominate" numbers under the same head, and the very plain demonstration of the rule for the division of fractions—both of which are, to us, *original*—make the work an invaluable one to teachers and students who are desirous to teach or study arithmetic as a science as well as an art.

(Signed,) D. H. MAHAN, Prof. Engineering.
W. H. C. BARTLETT, Prof. Nat. Phil.
A. E. CHURCH, Prof. Mathematics.

United States Military Academy, Jan. 18, 1847.

PRACTICAL GEOMETRY AND MENSURATION.

The design of this work is to afford schools and academies an Elementary Text-Book of a practical character. The introduction into our schools, within the last few years, of the subjects of Natural Philosophy, Astronomy, Mineralogy, Chemistry, and Drawing, has given rise to a higher grade of elementary studies; and the extended application of the mechanic arts calls for additional information among practical men. In this work all the truths of Geometry are made accessible to the general reader, by omitting the demonstrations altogether, and relying for the impression of each particular truth on a pointed question and an illustration by a diagram. In this way it is believed that all the important properties of the geometrical figures may be learned in a few weeks; and after these properties have been once applied, the mind receives a conviction of their truth little short of what is afforded by rigorous demonstration. The work is divided into seven books, and each book is subdivided into sections.

In Book I., the properties of the geometrical figures are explained by questions and illustrations.

In Book II. are explained the construction and uses of the various scales; and also the construction of geometrical figures. It is, as its title imports, Practical Geometry.

Book III. treats of Drawing. Section I., of the Elements of the Art; Section II., of Topographical Drawing; and Section III., of Plan Drawing.

Book IV. treats of Architecture—explaining the different orders, both by descriptions and drawings.

Book V. contains the application of the principles of Geometry to the Mensuration of Surfaces and Solids. A separate rule is given for each case, and the whole is illustrated by numerous and appropriate examples.

Book VI. contains the application of the preceding Books to Artificers' and Mechanics' work. It contains full explanations of all the scales—the uses to which they are applied—and specific rules for the calculations and computations which are necessary in practical operations.

Book VII. is an introduction to Mechanics. It explains the nature and properties of matter, the laws of motion and equilibrium, and the principles of all the simple machines.

ELEMENTARY ALGEBRA.

This work is intended to form a connecting link between Arithmetic and Algebra, and to unite and blend, as far as possible, the reasoning on numbers with the more abstract method of analysis. It is intended to bring the subject of Algebra within the range of our common schools, by giving to it a practical and tangible form. It begins with an introduction, in which the subject is first treated mentally, in order to accustom the mind of the pupil to the first processes; after which, the system of instruction assumes a practical form. The definitions and rules are as concise and simple as they can be made, and the reasonings are as clear and concise as the nature of the subject will admit. The strictest scientific methods are always adopted, for the double reason, that what is learned should be learned in the right way, and because the scientific methods are generally the most simple.

ELEMENTARY GEOMETRY.

This work is designed for those whose education extends beyond the acquisition of facts and practical knowledge, but who have not the time to go through a full course of mathematical studies. It is intended to present the striking and important truths of Geometry in a form more simple and concise than is adopted in Legendre, and yet preserve the exactness of rigorous reasoning. In this system, nothing has been omitted in the chain of exact reasoning, nothing has been taken for granted, and nothing passed over without being fully demonstrated The work also contains the applications of Geometry to the Mensuration of Surfaces and Solids.

SURVEYING.

In this work it was the intention of the author to begin with the very elements of the subject, and to combine those elements in the simplest manner, so as to render the higher branches of Plane Surveying comparatively easy. All the instruments needed for plotting have been carefully described, and the uses of those required for the measurement of angles are fully explained. The Conventional Signs adopted by the Topographical Bureau, and which are now used by the United States Engineers in all their charts and maps, are given in full. An account is also given of the manner of surveying the public lands; and although the method is simple, it has nevertheless been productive of great results. The work also contains a Table of Logarithms—a Table of Logarithmic Sines—a Traverse Table, and a Table of Natural Sines—being all the Tables necessary for Practical Surveying

The Collegiate Course.

I. **DAVIES' BOURDON'S ALGEBRA.**
II. **DAVIES' LEGENDRE'S GEOMETRY AND TRIGONOMETRY.**
III. **DAVIES' ANALYTICAL GEOMETRY.**
IV. **DAVIES' DESCRIPTIVE GEOMETRY.**
V. **DAVIES' SHADES, SHADOWS, AND PERSPECTIVE.**
VI. **DAVIES' DIFFERENTIAL AND INTEGRAL CALCULUS.**

The works embraced under the head of the "Collegiate Course," were originally prepared as text-books for the use of the Military Academy at West Point, where, with a single exception, they are still used. Since their introduction into many of the colleges of the country, they have been somewhat modified, so as to meet the wants of collegiate instruction. The general plan on which these works are written, was new at the time of their appearance. Its main feature was to unite the logic of the French School of Mathematics with the practical methods of the English, and the two methods are now harmoniously blended in most of our systems of scientific instruction.

The introduction of these works into the colleges was for a long time much retarded, in consequence of the great deficiency in the courses of instruction in the primary schools and academies: and this circumstance induced Professor Davies to prepare his Elementary Course.

The series of works here presented, form a full and complete course of mathematical instruction, beginning with the first combinations of arithmetic, and terminating in the higher applications of the Differential Calculus. Each part is adapted to all the others. The Definitions and Rules in the Arithmetic, have reference to those in the Elementary Algebra, and these to similar ones in the higher books. A pupil, therefore, who begins this course in the primary school, passes into the academy, and then into the college, under the very same system of scientific instruction.

The methods of teaching are all the same, varied only by the nature and difficulty of the subject. He advances steadily from one grade of knowledge to another, seeing as he advances the connection and mutual relation of all the parts: and when he reaches the end of his course, he finds indeed, that "science is but knowledge reduced to order."

DAVIES' BOURDON.

The Treatise on Algebra by M. Bourdon, is a work of singular excellence and merit. In France it is one of the leading text-books. Shortly after its first publication it passed through several editions, and has formed the basis of every subsequent work on the subject of Algebra.

The original work is, however, a full and complete treatise on the subject of Algebra, the later editions containing about eight hundred pages octavo. The time given to the study of Algebra in this country, even in those seminaries where the course of mathematics is the fullest, is too short to accomplish so voluminous a work, and hence it has been found necessary either to modify it, or to abandon it altogether. The Algebra of M. Bourdon, however, has been regarded only as a standard or model, and it would perhaps not be just to regard him as responsible for the work in its present form.

In this work are united the scientific discussions of the French with the practical methods of the English school, so that theory and practice, science and art, may mutually aid and illustrate each other. A great variety of examples have also been added in the late editions.

DAVIES' LEGENDRE.

Legendre's Geometry has taken the place of Euclid, to a great extent, both in Europe and in this country. In the original work the propositions are not enunciated in general terms, but with reference to, and by the aid of, the particular diagrams used for the demonstrations. It was supposed that this departure from the method of Euclid had been generally regretted, and among the many alterations made in the original work, to adapt it to the systems of instruction in this country, that of enunciating the propositions in general terms should be particularly named; and this change has met with universal acceptance.

To the Geometry is appended a system of Mensuration of Planes and Solids—a full treatise on Plane and Spherical Trigonometry—and a table of Logarithms, and Logarithmic Sines, Tangents, and Secants. The whole forms a complete system of Geometry with its applications to Trigonometry and Mensuration, together with the necessary tables.

ANALYTICAL GEOMETRY.

This work embraces the investigation of the properties of geometrical figures by means of analysis. It commences with the elementary principles of the science, discusses the Equation of the Straight Line and Circle—the Properties of the Conic Sections—the Equation of the Plane—the Positions of Lines in Space, and the Properties of Surfaces.

DESCRIPTIVE GEOMETRY.

Descriptive Geometry is intimately connected with Architecture and Civil Engineering, and affords great facilities in all the operations of Construction.

As a mental discipline, the study of it holds the first place among the various branches of Mathematics.

SHADES, SHADOWS, AND PERSPECTIVE.

This work embraces the various applications of Descriptive Geometry to Drawing and Linear Perspective.

DIFFERENTIAL AND INTEGRAL CALCULUS.

This treatise on the Differential and Integral Calculus, was intended to supply the higher seminaries of learning with a text-book on that branch of science. It is a work after the French methods of teaching, and in which the notation of the French school is adopted.

A CATALOGUE

OF THE

COLLEGES AND UNIVERSITIES

THAT HAVE ADOPTED

DAVIES' MATHEMATICAL WORKS.

(THE WHOLE SERIES, OR IN PART.)

THE UNITED STATES MILITARY ACADEMY.

Dartmouth College,	*Hanover,*	NEW HAMPSHIRE
University of Vermont,	*Burlington,*	VERMONT.
Norwich University,	*Norwich,*	"
Brown University,	*Providence,*	RHODE ISLAND.
Washington College,	*Hartford,*	CONNECTICUT.
Wesleyan University,	*Middletown,*	"
Columbia College,	*New York,*	NEW YORK.
Union College,	*Schenectady,*	" "
Hamilton Lit. and Theol. Instit.	*Hamilton,*	" "
Geneva College,	*Geneva,*	" "
University of New York,	*New York,*	" "
College of New Jersey,	*Princeton,*	NEW JERSEY.
University of Pennsylvania,	*Philadelphia,*	PENNSYLVANIA.
Lafayette College,	*Easton,*	"
Marshall College,	*Mercersburg,*	"
Dickinson College,	*Carlisle,*	"
Jefferson College,	*Canonsburg,*	"
Washington College,	*Washington,*	"
Alleghany College,	*Meadville,*	"
Western University,	*Pittsburg,*	"
Newark College,	*Newark,*	DELAWARE.
Georgetown College,	*Georgetown,*	DIST. OF COLUMBIA
Columbian College,	*Washington,*	" "
St. John's College,	*Annapolis,*	MARYLAND,
St. Mary's College,	*Baltimore,*	"
Mount St. Mary's College,	*Emmettsburg,*	"
Washington College,	*Lexington,*	VIRGINIA.

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Hampden-Sydney College,	*Prince Ed. Co.*	VIRGINIA.
University of Virginia,	*Charlottesville,*	"
Randolph Macon College,	*Boydtown,*	"
University of North Carolina,	*Chapel-Hill,*	NORTH CAROLINA
Davidson College,	*Mecklenburg,*	"
College of South Carolina,	*Columbia,*	SOUTH CAROLINA
University of Alabama,	*Tuscaloosa,*	ALABAMA.
Lagrange College,	*Lagrange,*	"
Louisiana College,	*Jackson,*	LOUISIANA.
Jefferson College,	*Washington,*	MISSISSIPPI.
Oakland College,	*Oakland,*	"
University of Tennessee,	*Nashville,*	TENNESSEE.
St. Joseph's College,	*Bardstown,*	KENTUCKY.
Centre College,	*Danville,*	"
Augusta College,	*Augusta,*	"
Cumberland College,	*Princeton,*	"
Georgetown College,	*Georgetown,*	"
Bacon College,	*Harrodsburgh,*	"
University of Ohio,	*Athens,*	OHIO.
Western Reserve College,	*Hudson,*	"
Oberlin Institute,	*Oberlin,*	"
Miami University,	*Oxford,*	"
Franklin College,	*New Athens,*	"
Kenyon College,	*Gambier,*	"
Granville College,	*Granville,*	"
Cincinnati College,	*Cincinnati,*	"
Woodward College,	*Cincinnati,*	"
Indiana College,	*Bloomington,*	INDIANA
South Hanover College,	*South Hanover,*	"
Wabash College,	*Crawfordsville,*	"
Illinois College,	*Jacksonville,*	ILLINOIS
Shurtleff College,	*Upper Alton,*	"
McKendrean College,	*Lebanon,*	"
University of St. Louis,	*St. Louis,*	MISSOURI
St. Charles College,	*St. Charles,*	"
Michigan University,	*Ann Arbour,*	MICHIGAN
The Military Academy,	*Georgetown,*	KENTUCKY.
Charleston College,	*Charleston,*	SOUTH CAROLINA

which it presents—clear and concise in its style, and entirely scientific and natural in its arrangement. The following features will, it is hoped, commend the work to public favor.

1. It is adapted to the *present state* of natural science; embraces a wider field, and contains a greater amount of information on the respective subjects of which it treats, than any other elementary treatise of its size.

2. It contains an engraving of *the Boston School set of philosophical apparatus*; a description of the instruments, and an account of many experiments which can be performed by means of the apparatus.

3. It is enriched by a representation and a description of the *Locomotive* and the *Stationary Steam Engines*, in their latest and most approved forms.

4. Besides embracing a copious account of the principles of Electricity and Magnetism, its value is enhanced by the introduction of the science of Pyronomics, together with the new science of Electro-Magnetism and Magneto-Electricity.

5. It is peculiarly adapted to the convenience of study and of recitation, by the figures and diagrams being first placed side by side with the illustrations, and then repeated on separate leaves at the end of the volume. The number is also given, where each principle may be found, to which allusion is made throughout the volume.

6. It presents the most important principles of science in a larger type; while the deductions from these principles, and the illustrations, are contained in a smaller letter. Much useful and interesting matter is also crowded into notes at the bottom of the page. By this arrangement, the pupil can never be at a loss to distinguish the parts of a lesson which are of primary importance; nor will he be in danger of mistaking theory and conjecture for fact.

7. It contains a number of original illustrations, which the author has found more intelligible to young students than those which he has met elsewhere.

8. Nothing has been omitted which is usually contained in an elementary treatise.

9. A full description is given of the Magnetic Telegraph, and the principles of its construction are fully explained.

10. For the purpose of aiding the teacher in conducting an examination through an entire subject, or indeed, through the whole book, if necessary, all the diagrams have been repeated at the end of the work, and questions proposed on the left-hand page immediately opposite. This arrangement will permit the pupil to use the figure, in his recitation, if he have not time to make it on the black-board, and will also enable him to review several lessons and recall all the principles by simply reading the questions, and analyzing the diagrams.

From the Wayne County Whig.

After a careful examination of this work, we find that it is well calculated for the purpose for which it is intended, and better adapted to the state of natural science at the present time, than any other similar production with which we are acquainted. The design of the author, in the preparation of this work, was to present to the public an elementary treatise unencumbered with matter that is not intimately connected with this science, and to give a greater amount of information on the respective subjects of which it treats, than any other school-book of an elementary character. The most remarkable feature in the style of this work is its extreme brevity. In the arrangement of the subject and the manner of presenting it, there are some peculiarities which are, in our opinion, decided improvements. The more important principles of this interesting science are given in a few words, and with admirable perspicuity, in a larger type; while the deductions from these principles, and the illustrations are contained in a smaller letter. Much useful and interesting matter is also given in notes at the bottom of the page.

This volume is designed expressly to accompany the *Boston School Set of Philosophical Apparatus*; but the numerous diagrams with which it is illustrated, are so well executed and so easily understood, that the assistance of the Apparatus is hardly *necessory* to a thorough knowledge of the science. The trustees of the Lyons Union School having recently procured a complete set of the above Apparatus, this work will now be used as a text-book in that institution.

LEICESTER ACADEMY, *April* 12, 1848.

MESSRS. A. S. BARNES & CO.:

Sirs:—I have examined Parker's Natural Philosophy, and am much pleased with it. I think I shall introduce it into the academy the coming term. It seems to me to have hit a happy medium between the too simple and the too abstract. The notes containing facts, and showing the reasons of many things that are of common occurrence in every-day life, seem to me to be a valuable feature of the work.

Very respectfully, yours, B. A. SMITH.

From the New York Evening Post.

Professor Parker's book embraces the latest results of investigation on the subjects of which it treats. It has a separate title for the laws of heat, or Pyronomics, which have been lately added to the list of sciences, as well as electro magnetism and magneto electricity. The matter is well arranged, and the style of statement clear and concise. The figures and diagrams are placed side by side with the text they illustrate, which is greatly for the convenience of the student. We cheerfully commend the book to the favorable attention of the public.

From the Albany Spectator.

This is a school-book of no mean pretensions and of no ordinary value. It is admirably adapted to the present state of natural science; and besides containing engravings of the Boston school set of philosophical apparatus, embodies more information on every subject on which it treats than any other elementary work of its size that we have examined. It abounds with all the necessary helps in prosecuting the study of the science, and as its value becomes known it cannot fail to be generally adopted as a text-book.

From the Newark Daily Advertiser.

A work adapted to the *present* state of natural science is greatly needed in all our schools, and the appearance of one meeting all ordinary wants must be hailed with pleasure by those who feel an interest in the cause of education. Mr. Parker's work embraces a wider field, and contains a greater amount of information on the respective subjects of which it treats, than any other elementary treatise of its size, and is rendered peculiarly valuable by the introduction of the science of Pyronomics, together with the new sciences of Electro-Magnetism and Magneto Electricity. We have seldom met with a work so well adapted to the convenience of study and recitation, and regard as highly worthy of commendation the care which the author has taken to prevent the pupil from mistaking theory and conjecture for fact. We predict for this valuable and beautifully printed w the utmost success.

From the New York Courier and Enquirer

"A School Compendium of Natural and Experimental Philosophy," by Richard Green Parker, has just been issued by Barnes & Co. Mr. Parker has had a good deal of experience in the business of practical instruction, and is, also, the author of works which have been widely adopted in schools. The present volume strikes us as having very marked merit, and we cannot doubt it will be well received.

New York, *May*, 1848.

Messrs. A. S. Barnes & Co.:

Gent.:—I have no hesitation in saying that Parker's Natural Philosophy is the most valuable elementary work I have seen: the arrangement of the subjects and the clearness of the definitions render it an excellent adjunct to a teacher. For the last seven years I have used it in various schools as a text-book for my lectures on Natural Philosophy, and am happy to find that in the new edition much important matter is added, more especially on the subjects of Electricity and Electro-Magnetism.

With respect, Gentlemen,

Your obedient servant,

GILBERT LANGDON HUME,

Teacher of Natural Philosophy and Mathematics in N. Y. city.

New York, *May* 2, 1848.

We have used Parker's Compend of Natural Philosophy for many years, and consider it an excellent work on the various topics of which it treats.

Yours, &c. FORREST & McELLIGOTT,

Principals of the Collegiate School

From the Lynchburg Virginian.

The volume before us strikes us as containing more to recommend it than any one of its class with which we are acquainted. It is adapted to the *present state* of natural science; embraces a wider field, and contains a greater amount of information on the respective subjects of which it treats, than any other elementary treatise of its size. It contains descriptions of the steam-engine, stationary and locomotive, and of the magnetic telegraph. It embraces a copious account of the principles of electricity and magnetism, under all their modifications, and is embellished by a vast number of illustrations and diagrams. There is appended a series of questions for examination, copious and pertinent

ROADS AND RAILROADS.

A MANUAL OF ROAD-MAKING:

Comprising the principles and practice of the Location, Construction, and Improvement of ROADS, (common, macadam, paved plank, &c.,) and RAILROADS. By W. M. GILLESPIE, A. M., Professor of Civil Engineering in Union College. Price $1.50.

Recommendation from Professor Mahan.

I have very carefully looked over Professor Gillespie's Manual of Road-Making. It is, in all respects, the best work on this subject with which I am acquainted; being, from its arrangement, comprehensiveness and clearness, equally adapted to the wants of Students of Civil Engineering, and the purposes of persons in any way engaged in the construction or supervision of roads. The appearance of such a work, twenty years earlier, would have been a truly national benefit, and it is to be hoped that its introduction into our seminaries may be so general as to make a knowledge of the principles and practice of this branch of engineering, as popular as is its importance to all classes of the community.

(Signed,)

D. H. MAHAN,
Professor of Civil Engineering in the Military Academy of the United States.

From a Report of a Committee of the American Institute.

This work contains in a condensed form, all the principles, both ancient and modern, of this most important art; and almost every thing useful in the great mass of writers on this subject. . . . . . Such a work as this performs a great service for those who are destined to construct roads—by showing not only what ought to be done, but what ought not to be done; thus saving immense outlay of money, and loss of time in experiments. . . . . The committee therefore, recommend it to the public.

From the American Railroad Journal.

The views of the author are sound and practical, and should be read by the people throughout the entire length and breadth of the land. . . . We recommend this Manual to the perusal of every tax-payer for road-making, and to the young men of the country, as they will find useful information in relation to each department of road-making, which will surely be useful to them in after-life.

From Silliman's American Journal of Science.

If the well-established principles of Road-Making, which are so plainly set forth in Prof. Gillespie's valuable work, and so well illustrated, could be once put into general use in this country, every traveller would bear testimony to the fact that the author is a great public benefactor.

From the Journal of the Franklin Institute.

This small volume contains much valuable matter, derived from the best authorities, and set forth in a clear and simple style. For the want of information which is contained in this Manual, serious mistakes are frequently made, and roads are badly located and badly constructed by persons ignorant of the principles which ought to govern in such cases. By the extensive circulation of such books as that now before us, and the imparting of sound views on the subject to the students of our collegiate institutions, we may hope for a change for the better in this respect.

From the Albany Cultivator.

The author of this work has supplied a desideratum which has long existed. Perhaps there is no subject on which information is more needed by the country in general than that of Road-Making. Prof. Gillespie has taken up the subject in a proper manner, beginning the work at the right place, and prosecuting it in systematic order to its completion.

From the New York Tribune.

It would astonish many "path-masters" to see how much they don't know with regard to the very business they have considered themselves such adepts in. Yet all is so simple, so lucid, so straight forward, so manifestly true, that the most ordinary and least instructed mind cannot fail to profit by it. We trust this useful and excellent volume may find its way into every village library if not into every school library, as well as into the hands of every man interested in road-making. Its illustrations are very plain and valuable, and we cannot doubt that the work will be a welcome visiter in many a neighborhood, and that bad roads will vanish before it.

From the Newark Daily Advertiser.

This elaborate and admirable work combines in a systematic and symmetrical form the results of an engineering experience in all parts of the Union, and of an examination of the great roads of Europe, with a careful digestion of all accessible authorities. The six chapters into which it is divided comprehend a methodical treatise upon every part of the whole subject; showing what roads ought to be in the vital points of direction, slopes, shape, surface, and cost, and giving methods of performing all the necessary measurements of distances, directions, and heights, without the use of any instruments but such as any mechanic can make, and any farmer use. Bridges, Railroads, and City Streets are also treated of at length and with good sense.

From the Vermont Chronicle.

To selectmen and others who may have any thing to do with these improvements, we would earnestly recommend the book named above. The author is a man of science, (Professor of Civil Engineering at Union College,) and his work embraces a full discussion of both the principles and practice of Road-Making. A little study of this work may often lead to results of importance to whole towns and counties.

From the Home Journal.

The author of this book holds a quill so skilful and dainty in light literature, that we were not prepared with laurels to crown him for a scientific work; but we see, by the learned critics, that this fruit of his study of his profession as an engineer, is very worthy of high commendation, and a valuable addition to the useful literature of the day.

MRS. EMMA WILLARD'S

SERIES OF SCHOOL HISTORIES AND CHARTS.

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The *Hon. Daniel Webster* says, of an early edition of the above work, in a letter to the author, "*I keep it near me, as a Book of Reference, accurate in facts and dates.*"

WILLARD'S AMERICAN CHRONOGRAPHER,

DESIGNED TO ACCOMPANY WILLARD'S HISTORY OF THE UNITED STATES.

To measure time by space is universal among civilized nations, and as the hours, and minutes, and seconds of a clock measure the time of a day, so do the centuries, tens, and single years of this Chronographer, measure the time of American History. A general knowledge of chronology is as indispensable to history, as a general knowledge of latitude and longitude is to geography. But to learn single dates, *apart* from a general plan of chronology addressed to the eye, is as useless as to learn latitudes and longitudes without reference to a map. The eye is the only medium of permanent impression. The essential point in a date, is to know the *relative* place of an event, or how it stands in time compared with other important events. The scholar in the school-room, or the gentleman in his study, wants such a *visible plan of time* for the study of history, the same as he wants the visible plan of space, viz., a map for the study of geography, or of books of travels. Such is the object of *Willard's Chronographer of American History.*

Extract from a Report of the Ward School Teachers' Association of the City of New York.

The Committee on Books of the Ward School Association respectfully report:

That they have examined Mrs. Willard's History of the United States with peculiar interest, and are free to say, that it is in their opinion decidedly the best treatise on this interesting subject that they have seen. * *

As a school-book, its proper place is among the first. The language is remarkable for simplicity, perspicuity, and neatness; youth could not be trained to a better taste for language than this is calculated to impart. The history is so written as to lead to geographical examinations, and impresses by practice the habit to read history with maps. It places at once, in the hands of American youth, the history of their country from the day of its discovery to the present time, and exhibits a clear arrangement of all the great and good deeds of their ancestors, of which they now enjoy the benefits, and inherit the renown. The struggles, sufferings, firmness, and piety of the first settlers are delineated with a masterly hand.

The gradual enlargement of our dominions, and the development of our national energies, are traced with a minute accuracy, which the general plan of the work indicates.

The events and achievements of the Revolution and of the last war, are brought out in a clear light, and the subsequent history of our national policy and advancement strikingly portrayed, without being disfigured by that tinge of party bias which is so difficult to be guarded against by historians of their own times.

The details of the discovery of this continent by Columbus, and of the early settlements by the Spaniards, Portuguese, and other European nations, are all of essential interest to the student of American history, and will be found sufficiently minute to render the history of the continent full and complete. The different periods of time, together with the particular dates, are distinctly set forth with statistical notes on the margin of each page,—and these afford much information without perusing the pages.

The maps are beautifully executed, with the locality of places where particular events occurred, and the surrounding country particularly delineated. These are admirably calculated to make lasting impressions on the mind.

The day has now arrived when every child should be acquainted with the history of his country; and your Committee rejoice that a work so full and clear can be placed within the reach of every one.

The student will learn, by reading a few pages, how much reason he has to be proud of his country—of its institutions—of its founders—of its heroes and statesmen: and by such lessons are we not to hope that those who come after us will be instructed in their duties as citizens, and their obligations as patriots?

Your Committee are anxious to see this work extensively used in all the schools in the United States.

(Signed,)

SENECA DURAND,
EDWARD McELROY,
JOHN WALSH.

The Committee would respectfully offer the following resolution:

Resolved, That Mrs. Emma Willard's History of the United States be adopted by this Association, and its introduction into our schools earnestly recommended.

At a meeting of the Board of the Ward School Teachers' Association, January 20th, 1847, the above Resolution was adopted.—(Copied from the Minutes.)

From the Boston Traveller.

We consider the work a remarkable one, in that it forms the best book for general reading and reference published, and at the same time has no equal, in our opinion, as a text-book. On this latter point, the profession which its author has so long followed with such signal success, rendered her peculiarly a fitting person to prepare a text-book. None but a practical teacher is capable of preparing a *good* school-book; and as woman has so much to do in forming our early character, why should her influence cease at the fireside—why not encourage her to exert her talents still, in preparing school and other books for after years? No hand can do it better.

The typography of this work is altogether in good taste.

From the Cincinnati Gazette.

Mrs. Willard's School History of the United States.—It is one of those rare things, a good school-book; infinitely better than any of the United States Histories fitted for schools, which we have at present. It is quite full enough, and yet condensed with great care and skill. The style is clear and simple—Mrs. Willard having avoided those immense Johnsonian words which Grimshaw and other writers for children love to put into their works, while, at the same time there is nothing of the *pap* style about it. The arrangement is excellent the chapters of a good length; every page is dated, and a marginal index makes reference easy. But the best feature in the work is its series of maps; we have the country as it was when filled with Indians; as granted to Gilbert; as divided at the time the Pilgrims came over; as apportioned in 1643; the West while in possession of France; the Atlantic coast in 1733; in 1763; as in the Revolution, with the position of the army at various points; at the close of the Revolutionary War; during the war of 1812-15; and in 1840: making eleven most excellent maps, such as every school history should have. When we think of the unintelligible, incomplete, badly written, badly arranged, worthless work of Grimshaw which has been so long used in our schools, we feel that every scholar and teacher owes a debt of gratitude to Mrs. Willard. Miss Robins has done for English History, what Mrs. Willard has now done for American, and we trust these two works will be followed by others of as high or higher character. We recommend Mrs. Willard's work as better than any we know of on the same subject; not excepting Bancroft's abridgment. This work, followed by the careful reading of Mr. Bancroft's full work, is all that would be needed up to the point where Bancroft stops; from that point, Pitkin and Marshall imperfectly supply the place, which Bancroft and Sparks will soon fill.

From the United States Gazette.

Mrs. Willard is well known throughout the country as a lady of high attainments, who has distinguished herself as the Principal of Female Academies, that have sent abroad some of the most accomplished females of the land.

The plan of the authoress is to divide the time into periods, of which the beginning and the end are marked by some important event, and then care has been taken to make plain the events of intermediate periods. The style is clear, and there appears no confusion in the narrative. In looking through the work, we do not discover that the author has any early prejudices to gratify. The book, therefore, so far as we have been able to judge, may be safely recommended as one of great merit, and the maps and marginal notes, and series of questions, give additional value to the work.

From the Newburyport Watchman.

An Abridged History of the United States: By Emma Willard.—We think we are warranted in saying, that it is better adapted to meet the wants of our schools and academies in which history is pursued, than any other work of the kind now before the public.

The style is perspicuous and flowing, and the prominent points of our history are presented in such a manner as to make a deep and lasting impression on the mind.

We could conscientiously say much more in praise of this book, but must content ourselves by heartily commending it to the attention of those who are anxious to find a good text-book of American history for the use of schools.

From the Albany Evening Journal.

Willard's United States.—This work is well printed on strong white paper, and is bound in a plain substantial manner—all-important requisites in a school-book. The text is prepared with equal skill and judgment. The memory of the youthful student is aided by a number of spirited illustrations—by no means unimportant auxiliaries—while to lighten the labors of the teacher, a series of questions is adapted to each chapter. Nor is its usefulness limited to the school-room As a book of reference for editors, lawyers, politicians, and others, where dates and facts connected with every important event in American History may be readily found, this little book is truly valuable.